Paul Rubin - Hydrogeologist

EXHIBIT 7

NORMA FIORENTINO, et al.,	)	3:09-cv-02284
	)	
Plaintiffs,	)	Hon. John E. Jones III
v.	)	
	)	Magistrate Paul C. Carlson
CABOT OIL & GAS	)	
CORPORATION and GAS SEARCH	)	
DRILLING SERVICES CORP.,	)	
	)	
Defendants.	)	

AFFIDAVIT IN OPPOSITION TO DEFENDANTS' MOTIONS FOR SUMMARY JUDGMENT AND
PARTIAL SUPPLEMENTAL EXPERT REPORT

I, Paul Rubin, certify pursuant to the penalty of perjury under 28 U.S.C. 1746, that:

1. My name is Paul Rubin. Hydrogeologist, Independent Consultant, and President of HydroQuest.
2. I have over thirty years of experience studying groundwater and surface water contamination. I have provided expert testimony on hydraulic fracturing before the New York State Assembly and Senate and county legislatures, have served as a panel member in hydraulic fracturing forums, have authored technical reports on hydraulic fracturing and Fact Sheets on the technology and its impacts for the Delaware Riverkeeper Network, Sierra Club, and other environmental groups in New York State, The Commonwealth of Pennsylvania, West Virginia and Ohio.
3. I have had opportunity to analyze hundreds of well water samples in Susquehanna County, regions of New York State and other states and municipalities throughout the Northeast and other regions of the United States.

4. In all instances where I have sampled surface and groundwater I utilize certified laboratories and sampling and analytical techniques consistent with the state and federal protocols and standards within my profession, including chain-of-custody procedures.

5. I sampled the well water of Nolen Scott Ely, a remaining pro se plaintiff in this case on November 22, 2011.

6. I submit this affidavit in support in support of Mr. Ely, all of the remaining pro se plaintiffs litigation claims, and in opposition to defendants' motions for summary judgment, and partial rebuttal of defendants' expert reports with respect to the company's denials of contamination of plaintiffs' water wells and assertions that their water is fit for human consumption, which opinions should be given little credence.

7. Two curricula vita are attached for further reference as to my educational and professional background. **Exhibit A** is broad in nature. **Exhibit B** details recent work I have conducted relative to gas industry practices and hydrogeologic concerns.

8. At their request, in 2011, I provided to Napoli Bern Ripka Scholnick & Associates, plaintiffs' former attorneys, with a November 23, 2011 affidavit in support of the Petioners' supersedeas and temporary supersedeas petitions generally directed to the litigation involving over a dozen households including that of the Ely's, Huberts and of Kenneth R. Ely, which report is attached hereto as **Exhibit C** (without Exhibits) and referenced by incorporation. This affidavit concludes that Cabot's whole house treatment systems are inadequate to permanently replace or restore the Petitioners' water supplies.

9. I learned from pro se plaintiffs that this Court had ordered that supplemental expert reports were to have been filed by June 3th. My understanding is that Mr. Ely received defendants' expert reports sometime during the week of April 29th. I received them from Mr. Ely within

the following week. I alerted Mr. Ely that as much as I wished to meet that deadline and that I would do the best I could to do so, my other assignments would probably not allow me to do the thorough job that another month would allow me given the voluminous paper inundation by Cabot through their experts. I know that pro se plaintiffs were to have made a request of the Court for me in that regard.

10. I have been provided the pleadings and the motions and deposition testimony, and took particular note in reviewing, the after the fact statements of selected Susquehanna County residents, at the behest of the gas company, with respect to historical presence of essentially explosive background levels of methane in their well water. I have reviewed pertinent data and discovery as well as defendants' expert reports and statements with regard to defendants' denial that their activities have caused water contamination, the water is fit and safe to drink or in the alternative, if the water is not fit or safe to drink, whatever contamination that exists can be readily mitigated or corrected through use of what Cabot and the Pennsylvania Department of Environmental Protection refers to as a "whole house treatment system," in essence, a methane separator system using ozone together with a bunch of filters.

11. I have also carefully studied all of the Consent Orders and Agreements entered between Cabot Oil & Gas Corp. and Gas Search Drilling Services Corporation, its' subsidiary drilling company (collectively, Cabot) and the DEP in 2009 and 2010. All told, it is my opinion to a reasonable degree of hydrogeological certainty that more likely than not Cabot's opinions are without scientific merit. I intend to testify at the time of trial of this matter that, to a reasonable degree of hydrogeological certainty, it is more likely than not that: i) the aquifer feeding the Ely and Hubert water wells has been compromised and contaminated by Cabot gas drilling and waste disposal operations in the area; ii) that such contamination will last for

decades, a century or more; iii) that such contamination includes elevated concentrations of natural gas; iv) that such contamination includes evidence of contamination from drilling and waste disposal activities; v) that any water test (sampling and analysis) is simply a snapshot in time, and that contaminants, combinations of contaminants and concentrations of contaminants individually and in combination are part of a dynamic that changes according to various factors, even on a daily basis; vi) that significant changes in groundwater chemistry occurred as a result of drilling related activities; vii) that the type of damage to the aquifer supplying the Ely and Hubert families' well water supplies is not permanently or properly treated with a methane separator attached to a variety of filters; viii) that in order to restore the Ely-Hubert water to a safe level, their water would literally have to be vaporized, in such a way that all proprietary and other low level contaminants are removed.

12. The bases of my opinions, in addition to the above, is water sampling data demonstrating that the Ely-Hubert well water supplies were adversely impacted by chemicals directly related to natural gas drilling activity, as documented in numerous chemical analyses, including secondary Maximum Contaminant Level (MCL) violations. Some of these violations and health concerns related to potential chronic exposure to low-level gas industry chemicals are discussed in a press statement I prepared (**Exhibit D**).

13. Data is presented from November 22, 2011 water sampling conducted by HydroQuest, as well as other analyses, which demonstrate continued contamination by aluminum, iron, and manganese among other potentially toxic substances.

14. In addition, a host of other chemicals were detected at concentrations either below MCL limits or with no MCL during the 1-26-12 EPA sampling event. Some are followed by letter

notes of J (present, but value is an estimate) or B (qualifier not identified, possibly present in lab. blank which makes its detection uncertain).

15. These chemicals include low levels of arsenic, barium, chromium, lead, strontium, bis (2-ethylhexyl) phthalate [B,J], butylbenzyl phthalate [B,J], di-n-butyl phthalate [B,J], caprolactam [J], fluoranthene [J], fluorene [J], pyrene [J], acetone [B,J], and fluoride. Bis (2-ethylhexyl) phthalate is a non-naturally occurring chemical associated with hydraulic fracturing.

16. The HydroQuest sampling event of November 22, 2011of the Ely well water supply also found lead levels that exceeded the recommended MCL (0.029 mg/l vs. 0.005 mg/l), as did arsenic (0.015 mg/l vs. 0.010 mg/l). A consultant for Cabot (Saba) erroneously seeks to discredit data found from this sampling event. Saba seeks to make a case that sample results obtained from the Scott Ely well on November 22, 2011 are outlier values that should be discarded based on his assumption that the well was being pumped at too high a rate at the time of sample collection, thus making it unusually turbid. As supporting evidence, Saba uses two photographs I took when first looking at the well. Saba numbers these photographs as 1 and 2 on his Figure 8.2.3 and then draws conclusions based on these photographs. These photographs were taken on October 28, 2011 at 11:33 am and 12:05 pm, respectively – not at the time of water collection. On November 22, 2011, when I collected water for analysis from the Scott Ely well, the flow rate was substantially reduced in an attempt to minimize turbidity, get field parameter values, and to obtain water samples representative of what the Ely family would drink if they used their well water. Even at a low pumping rate, the water was turbid. Unfiltered chemicals, at high concentrations (e.g., Al), would have been ingested had the Ely's been drinking their well water. Thus, the data set Saba seeks to discredit

reflects what was present in the groundwater on the date of sample collection. The lack of important basic fact checking, followed by unfounded conclusions, is cause to reject the Saba report.

17. Analyses of Cabot frack water have found many chemicals including barium, iron, manganese, magnesium, strontium, sodium, and lithium. The widely variable range of metals values points out the uncertain risks of potentially ingesting elevated levels of known and unknown chemicals. Although health impacts are beyond the scope of this affidavit and beyond my hydrologic expertise, **Exhibit E** and its referenced supporting documentation provide excellent health-based information.

18. The consumption of water with constituents such as those identified in Scott Ely's well water poses a threat to human health. Dr. Ronald Bishop raises concerns regarding the quality of Dimock water supplies and potential adverse health impacts (**Exhibit F**). Sample HW-06 is the Scott Ely well water. Homeowners should not be subjected to drinking such water. In some instances, EPA derived trigger levels were exceeded for other chemicals (e.g., fluoride, arsenic, chromium, lithium, sodium).

19. Natural gas and contaminant transport pathways between deep gas horizons and freshwater aquifers are well documented. They include faults, joints, fracture zones, failed cement sheaths and casing material and poorly or not plugged wells (illustrated in **Exhibits G**). **Exhibit H** portrays likely contaminant migration vectors in failed sheath or unplugged portions of gas wells.

20. A key problem is not so much the leakage of contaminants through the shale, but leakage along vertical fractures produced or enlarged by fracking, into adjacent high-permeability beds. From there, the groundwater flow is concentrated and relatively rapid. Most fractures

(i.e., joints and faults) remain unidentified. For example, evidence of faulting is present in a quarry close to Carter Road (**Exhibit I**). Faults such as these may serve as important pathways that interconnect shallow and deep bedrock formations.

21. The Ely and Hubert residences obtain their groundwater from the same aquifer. The locations of these and other homeowner water supplies and the quarry discussed above are depicted on **Exhibits J and K**. Examination of the bedrock quarry along Carter Road reveals that the bedrock is extensively fractured and faulted. A rose diagram (**Exhibit L**) hereto depicts a prominent north-south fracture/joint orientation, with a less prominent east-west fracture orientation that connects major north-south fractures as mapped by HydroQuest. The rose diagram plot illustrates joint orientations within the 360 degrees of true north, similar to the face of a compass. The longer and wider the red wedge, the greater the number of times a particular joint orientation was measured. The greater the abundance and spacing of joints, the more likely it is that they will be interconnected with other joints and conduct groundwater flow. On this graph, joint orientations are plotted only within the first 180 degrees of the compass. However, it should be recognized that these near vertical joints are linear and, as such, extend outward into the southern and western portions of the compass along the same linear orientations depicted.

22. In addition to interconnected fractures, the Carter Road Quarry reveals that the area has been faulted on at least two occasions, as is illustrated on photo based **Exhibit I**. Fracture/joint and fault plane interconnections provide the most likely contaminant, natural gas, and sediment transport pathways between the Gesford gas wells 3 and 9 and one or more homeowner wells. **Exhibit M** provides example joint sets properly oriented in the area to show likely flow vectors.

23. Joint networks are well known and extensive throughout the Appalachian Basin. Single joints in the Appalachian Basin are known to extend for thousands of feet or more. The joint orientations mapped in the Carter Road quarry are consistent with fracture orientations found throughout the Appalachian Basin (**Exhibit N**). The distance between the Gesford wells 3 and 9, the nearest and most likely sources of groundwater contamination, and the nearby Scott Ely well is on the order of 600 to 700 feet. Fracture interconnections along north-south and east-west orientations would have little difficulty providing bedrock pathways from the Gesford wells to the nearby homeowner well discussed (approximately 300 feet deep). Faults, perhaps those depicted in a report figure, or others not yet mapped, may serve to interconnect closely-spaced joints.

24. Highly variable methane concentrations in the Scott Ely and Hubert wells strongly suggest an unnatural fluctuation that may correlate with gas field activities. The "Recommended action level from the Office of Surface Mining Reclamation and Enforcement – Appalachian Regional Coordinating Center, Pittsburgh, PA (September 2001)" is 28,000 ug/l. Natural upward gas movement is generally very small because (A) the gas is normally trapped in low-permeability materials such as shale, and (B) in old deposits there has been plenty of time for the gas to have migrated in the past. Methane migration occurs when there is a gas concentration gradient between subsurface deposits (high concentration) and the surface air (essentially zero concentration). The leakage rate is a function of concentration difference, distance of migration, permeability of the surrounding material, and nature of the gas (composition, temperature, etc.). Reports of natural gas seeps and methane in water wells prior to fracking are evidence for this process. Many natural examples are concentrated in valleys. This is apparently because valleys afford the shortest paths for rising gases and,

probably much more importantly, they tend to be located along zones of significant fractures, which provide low-resistance paths for gas migration. In sharp contrast to the small upward movement of natural gas that naturally occurs at a very slow rate, fluctuating gas concentrations found in the Scott Ely well may correspond to an unnaturally rapid rate of methane migration. The most likely reason for this is because drilling a gas well enhances the gas flow rate (mainly into the well) because it shortens the migration distance and forms/enlarges fractures that allow gas flow. Thus, as wells get deeper, more numerous, and interconnect previously isolated gas-rich fractures via horizontal laterals, the methane leakage increases. This is the purpose of hydraulic fracturing. Fracking has the most impressive effect on gas migration as it will serve to hydraulically interconnect old and new oil and gas wells, joints, fracture zones, faults and failed or failing boreholes. As long as there is a source of higher pressure and a destination of lower pressure (e.g., wellbore, open fracture, fault, reservoir surface) gas migration will occur as gas seeks to achieve equilibrium conditions. Gas migration will occur at any depth where a pressure differential is encountered (i.e., when a drill bit breaches a rock layer that serves to confine natural gas within a porous zone such as a joint, fault, bedding plane or fracture; gas will rapidly flow to a zone of lower pressure). Unnaturally rapid methane migration can occur when drilling encounters previously confined methane and one or more release points become available. High methane concentrations found in the Scott Ely well, and not previously observed, probably resulted when one or more Gesford gas wells interconnected bedrock fractures and faults with the open boreholes present in homeowner wells. Pathways from gas wells include debonded, channeled and cracked cement sheath and casing material, upward to fractures and faults (**Exhibit O**). Ingraffea details specific problems with Dimock wells, including the

Gesford wells, which likely contributed to the contamination of the Scott Ely water supply. Once fracture pathways were opened via the drilling or hydraulic fracturing process, gas migration readily ensued from gas-bearing strata, following available pathways toward release points with lower gas pressures. As long as a source of higher pressure and a release point of lower pressure exist, gas migration will occur – this is the mechanism of gas production. In recognition of this physical fact, gas companies have installed gas vents on homeowner wells in some areas to reduce the risk of explosions. The same pathways that are hydraulically connected to gas wells that provide open avenues for gas migration are also available for migration of toxic and carcinogenic gas industry chemicals.

25. Gas industry chemicals injected into gas-rich shale formations at the Gesford wells will and apparently have migrated as one or more contaminant plumes to the freshwater aquifer tapped by a nearby homeowner's well.

26. "*Hydraulic fracturing poses a serious threat to groundwater quality, not only in the vicinity of the drilling site, but also in the entire down-gradient part of the groundwater flow system. Although the main injection of contaminants takes place thousands of feet below the surface, groundwater flow inevitably carries them laterally and then upward into major neighboring river valleys over periods of years to hundreds of years, tailing off for possibly thousands of years. In the Appalachians, the valleys are where most people live. The* ***contaminants*** *are widely dispersed, but they* ***pose a low-level threat to health****, especially when thousands of fracked wells are involved.*" (Palmer; **Exhibits P** [p. 8] **and Q** [p. 3]) Dr. Arthur N. Palmer is one of the most frequently cited and highly respected hydrologists in the world.

27. Water clarity in the Ely well exhibits unnatural color relative to the normal, clear, groundwater that was present for years before Cabot installed gas wells nearby (S. Ely, pers.

comm. with Paul Rubin). Mr. Ely's water is the brown color of chocolate milk, five times the maximum allowable PA MCL Safe Drinking Water standard (75 vs. 15 color units) for color. Water chemistry data from testing of Mr. Ely's well documents widespread change in groundwater chemistry from pre- to post-drilling conditions (**Exhibits J and K**). pH concentration, for example, has increased orders of magnitude. The significance and important of this is addressed in depth in **Exhibit R** (HydroQuest Hubert affidavit; text provided; most exhibits incorporated within this affidavit). Simply put, Cabot's drilling activities and drill cuttings waste disposal methodology has radically altered groundwater chemistry. Furthermore, this exhibit discusses why the groundwater is not safe to drink. **Exhibit R** compliments **Exhibit S** (text provided; most exhibits incorporated within this affidavit). Both are hereby incorporated by reference, along with all other Exhibits related to this affidavit.

28. Prior to gas drilling activities, Scott Ely's groundwater was clear, potable, and did not require filtration. Microscopic analysis of particles now present in this water revealed the presence of quartz (**Exhibits T and U**), which contributes to the water's high turbidity. The change in water clarity coincides with Cabot gas drilling activities at the Gesford wells. It is likely that some of the changed groundwater flow conditions (i.e., sediment entrainment and mobilization) occurred from outward fluid losses during the early well drilling.

29. In terms of chemical parameters, groundwater sampling by HydroQuest found lead and manganese at 5.8 and 10 times that of recommended State primary and secondary MCL, respectively, and arsenic at 1.5 times the State MCL. Aluminum was detected at a concentration of 28 mg/l, some 140 times the State MCL. This is cause for great concern. Aluminum is a potent neurotoxin that may be linked to dementia, including health symptoms

resembling Alzheimer's disease. Similarly, iron was detected at 34 mg/l, some 113 times the State MCL Safe Drinking Water standard.

30. The high pH of homeowner water indicates the presence of significant, other frack-related chemicals that may not be adequately identified – chemical compounds that do not individually have MCLs – chemicals that potentially present long-term chronic exposure to toxins and carcinogens. Chemical pH testing of one particular homeowner's water, on numerous dates on and after 1-06-09, conducted by Cabot, HydroQuest and others has consistently found the pH of their water to generally be in the range of 8.61 to 9.81 after January 6, 2009, with most determinations being in excess of 9.0. The MCL range for pH is 6.5 to 8.5. Gesford 3 well drilling to the Marcellus Shale (6,636 ft. to 6,962 ft.) occurred over a period of time ranging from September 25, 20008 to March 8, 2009.

31. Importantly, baseline chemical testing of Ely well water conducted on July 9, 2008 documented the well's original, pre-drilling, pH of 6.9. The significant increase in the pH of homeowner water occurred shortly after spudding of the Gesford wells. **Exhibits J and K** document the radical change in groundwater pH from pre- to post-drilling conditions. This is discussed in detail in **Exhibits R and S**.

32. The Saba report provides analytical data documenting water chemistry concentrations in the Kenneth Ely groundwater supply on September 27, 2008. pH was analyzed on-site with a Corning pH meter and found to be 6.30. This value is consistent with other nearby background (i.e., pre-drilling) pH values (Exhibit C of Hubert affidavit). This value reflects the pH of the groundwater before gas drilling operations resulted in an increase in pH of almost three orders of magnitude (see **Exhibit K**). The widespread nature of the change in

groundwater pH provides documentation of adverse impact stemming from gas drilling operations.

33. To a reasonable degree of hydrogeologic certainty, the timing of this unnatural increase in groundwater pH correlates precisely to Cabot's gas well development activities. The unnaturally high pH and its almost 1000-fold increase occurs coincident with Cabot's site development. It would not be safe for these homeowners to drink this groundwater now or ever. Clearly, an assortment of Cabot gas company chemicals caused this unnatural change – thereby documenting that hydraulically open pathways exist between gas wells and homeowner wells. Thus, the presence of hundreds of possible chemicals, many toxic, in the groundwater environment – especially in the absence of MCLs that address them individually or collectively – poses a health risk that no one should be asked to assume. Any "whole house water treatment system" that has not been demonstrated to be capable of removing ALL the chemicals placed down hole and those buried in on-site waste pits AND a host of unknown proprietary chemicals that are likely to appear in variable concentrations over time should not be used. Furthermore, such a treatment system, short of virtually evaporating the water to remove all chemicals, is not a permanent replacement for a once excellent water supply. The inherent health risks involved in relying on whole house water treatment systems in this situation are too great to ask anyone to assume. In addition, to do so would set a very bad and unfounded precedent. A suitable, permanent, replacement water supply would be extension of a distant water supply line to all adversely impacted homeowners.

34. Another important health-based aspect of potential chemical Plaintiff exposure to gas field contaminants stems from a combination of losses of drilling fluid chemicals during the drilling process or from outward leaching of voluminous drill cuttings waste buried at gas

well sites. The later practice, while allowed within existing PA regulations, sets the stage for the slow release of chemical time bombs that will assuredly and adversely impact down-gradient groundwater and surface water quality. Much of the Plaintiffs water quality problems may stem from these chemical losses during the drilling process and/or excursion of contaminants outward from buried drill cuttings waste pits at well sites. The triangles on **Exhibit M**, while not placed exactly right, were placed to represent the presence of one or more drill cuttings waste burial sites at Cabot gas well sites. The upper shallow groundwater flow segment of **Exhibit V** depicts the means by which buried cuttings waste at Cabot well sites may flow down-gradient into Plaintiffs wells. The red arrows on **Exhibit M** represent the shallow groundwater flow vectors from gas wells and buried drill cuttings pits directly to homeowner water supplies. Furthermore, it is highly likely that the drilling process itself has contributed to contamination of Plaintiffs groundwater.

35. Large volumes of chemically-laced bedrock drilling cuttings have been buried at Cabot gas well sites in Dimock hydrologically close Plaintiffs wells where they are now poised to contaminate groundwater and surface water resources. High metals, TDS, sodium, and radionuclide concentrations characterize much of the drilling waste solids materials.

36. On behalf of the Delaware Riverkeeper Network, HydroQuest is conducting a review of chemicals used in Cabot's gas well drilling operations in the Dimock, PA area by examining documents required for disposal of drilling related bedrock cuttings and fluids. Particular attention was paid to laboratory analyses of metals detected in these cuttings and fluids, with lesser attention focused on the presence of volatile organics and other chemicals. The analyses examined are considered to be representative of drilling chemicals buried by Cabot at numerous gas well sites in Dimock, PA and elsewhere. A spreadsheet (**Exhibit W**; shared

here with permission) is currently under construction (i.e., not finalized) to facilitate review and correlation of Cabot drilling waste materials with four recent analyses of homeowner well water chemistry, as well as a few earlier homeowner analyses. Columns P, Q, and U are Scott Ely water analyses. It is noted here and on the spreadsheet that while the particular analyses reviewed were of material removed from gas well sites that it is reasonable to assume that Cabot's drilling and chemical materials were similar between well sites in keeping with their experience. Because of the limited nature of this initial, ongoing, data review, it is also of value to compare drilling-related chemical data with hydraulic fracturing related chemicals documented in a major study of gas industry chemical use (i.e., the Hayes study). Both drilling fluid and hydraulic fracturing waters exhibit elevated concentrations of heavy metals, which are likely to migrate in shallow and deep groundwater flow systems.

37. Review of chemical compounds found in only a few of the homeowner wells in Dimock, PA shows that many of the chemicals present in drilling waste material are present in homeowner water supplies (see Table 1 below shared from HydroQuest work for Delaware Riverkeeper). Some of the chemicals that have been detected in homeowner water supplies do not have groundwater standards. In addition, the presence and concentrations of certain chemicals in homeowner wells is almost certainly from gas industry activities (e.g., aluminum, arsenic, barium, boron, chromium, copper, iron, lithium, magnesium, nickel, sodium, strontium, zinc). Lithium, for example, does not naturally occur in an elemental form due to its high reactivity. The presence of some of these metals and elevated groundwater pH (see discussion above) provide evidence of contaminant transport between gas well sites and homeowner water supplies.

Table 1: Chemical Components [ND: Not Detected NA: Not Analyzed]

Chemical Component Listed in Exhibit W	**Chemical Component Found in Cabot Drill Cuttings or Fluids**	**Chemical Component Found in any Exhibit W Homeowner Well**	**Chemical Listed in 750 Hydraulic Fracturing Compounds of Appendix A of the 2011 Congressional Report**	**Approximate # of 750 List Compounds containing Chemical Component**
Aluminum	Yes	Yes	Yes and with other assorted Al compounds	76
Aluminum	Yes	Yes	Yes, as aluminum oxide	48
Antimony	ND & NA	Yes	Yes, with other antimony compounds	9
Arsenic	Yes	Yes	No	0
Barium	Yes	Yes	Yes, as barium sulfate	3
Beryllium	Yes	NA & ND	No	0
Boron	Yes	Yes	Yes, in assorted compounds	54
Bromide	Yes	NA & ND	Yes, in alkaline bromide salts	3
Cadmium	Yes	NA & ND	No	0
Calcium	Yes	Yes	Yes, in assorted compounds	51
Chromium	Yes	Yes	Yes, as chromates & chromium acetate	2
Cobalt	Yes	Yes	Yes, as cobalt acetate	1
Copper	Yes	Yes	Yes, and in assorted compounds	7
Fluoride	Yes	Yes	Yes, in two compounds	11
Iron	Yes	Yes	Yes, in assorted compounds including iron oxides; hematite, maghemite, magnetite	46
Lead	Yes	Yes	Yes	1
Lithium	Yes	Yes	No	0
Magnesium	Yes	Yes	Yes, in assorted compounds	47
Manganese	Yes	Yes	No	0
Mercury	Yes	ND & NA	No	0
Molybdenum	Yes	NA	No	0
Nickel	Yes	Yes	Yes, in one compound	2
Potassium	Yes	Yes	Yes, in assorted compounds	95
Selenium	Yes	ND & NA	No	0
Silver	Yes	NA & ND	No	0
Sodium	Yes	Yes	Yes, in assorted compounds and probably in assorted salts not included in column to right	338^+
Strontium	Yes	Yes	No	0
Thallium	Yes	NA & ND	No	0
Tin	NA & ND	NA & ND	No	0
Titanium	Yes	NA & ND	Yes, as organic titanate and as assorted compounds	25

Zinc	Yes	Yes	Yes, in assorted compounds	3

38. Chemicals documented in Cabot drill cuttings and fluids show a prevalence of metals, including aluminum, barium, calcium, iron, magnesium, and sodium with other lower concentrations of arsenic, chromium, potassium, and strontium. Highly elevated concentrations of sodium and total dissolved solids stand out, as do elevated pH concentrations in a number of the Cabot samples. Other chemical parameters are also present. Some of these same parameters have been documented in Dimock homeowner water samples. For example, the Ely groundwater samples exhibit elevated concentrations of sodium, total dissolved solids, pH, aluminum, and iron. In addition, other parameters found in drill cuttings and fluids have been documented in the Ely well water, including arsenic, potassium, and strontium. The presence of these chemicals is consistent with the chemicals used by Cabot in their drilling mud.

39. Pressurized injection outward into bedrock formations during drilling operations is a means by which drilling fluid chemicals may enter groundwater and ultimately discharge to surface water resources. Depending on when metals-rich drilling fluids are first used during gas well construction, pressurized injection into adjacent or overlying formations may lead to groundwater contamination long before wells are hydraulically fractured - especially if contact with freshwater aquifers occurs. During drilling operations drilling fluids are forced laterally outward into adjacent bedrock formations. If fractured and faulted bedrock conditions prevail (e.g., see **Exhibits I and L** of joints and faults in the Carter Road Quarry in Dimock, PA) fluids will be dispersed upward in the presence of upward pressure gradients. Significant quantities of drilling fluids are commonly lost outward, where chemically-laced fluids may then enter shallow and deep groundwater flow systems (**Exhibits G, H and V**). The loss of toxic drilling fluid into

bedrock joints, faults, bedding planes, voids, and conduits may be a significant source of groundwater contamination.

40. Natural groundwater chemistry in Dimock, PA has been unnaturally altered as a result of gas drilling related activities. Analysis of pre- and post-drilling groundwater chemistry in Dimock, PA by HydroQuest revealed a significant change in pH over a broad area. Data reviewed and analyzed for the Delaware Riverkeeper Network and shared here as **Exhibits J and K** and related text show that the chemistry of the Ely groundwater has been altered from that of calcium-bicarbonate rich groundwater to a highly alkaline (high pH) sodium-bicarbonate rich groundwater. Discussion follows.

41. Pollution by gas field chemicals has changed the pH and natural chemistry of groundwater tapped by a number of wells in the Dimock, PA area from below pH 7.3 prior to gas drilling activities (**Exhibit J**), up to pH 9.81 after gas well installations (**Exhibit K**). These two figures are very important because they show widespread change in groundwater chemistry in a gas field as a direct result of Cabot gas industry activities. Because pH is expressed using a logarithmic scale, a change of one full pH unit is a 10-fold increase, a change of two is a 100-fold increase, etc. The May 23, 2012 Ely water sample reports a laboratory pH value of 8.7. Other Ely pH values range up to 9.81, an almost three order of magnitude increase (i.e., 1000-fold) from a pre-drilling pH of 6.9. pH is an excellent indicator of overall groundwater chemistry, especially when it varies significantly from natural background levels – as it does in the Ely well water. The pH of water indicates directly the ratios of certain ionic species to one another if equilibrium is established. The pH of water represents the interrelated result of a number of chemical equilibria (Hem, 1970; Study and Interpretation of the Chemical Characteristics of Natural Water; Geological Survey Water-Supply Paper 1473). Since pH can

be affected by chemicals in the water, it is an important indicator of water that is changing or has changed chemically. Excessively high pH can be attained through the addition of high pH additives, most notably through the use of alkalinity additives that contain hydroxide or carbonate such as potassium hydroxide or sodium hydroxide. The detection of boron in Cabot drilling mud solids (e.g., Grosvenor sample: 21.5 mg/kg), drill cuttings solids (e.g., Hinckley sample: 23.4 mg/kg), drilling fluid pit water, drill cuttings leachate, flowback water, frac tank solids residuals, and the Ely water well (**Exhibit W**) also represents a likely contributing cause of post-drilling increases in groundwater pH. As an example, the addition of soluble borate to hydraulic fracturing fluids provides a pH in the range from about 8 to about 10 and a source for boron (Abstract EP 0225873 B1; Crosslinked fracturing fluids).

42. The May 2012 pH of the Ely well water is high and is consistent with other post gas well drilling groundwater pH values. The pH of other nearby groundwater, prior to completion of nearby gas wells, reveals a natural background pH below 7.3 (**Exhibit J**). pH provides an excellent means of examining the issue of water quality and altered groundwater chemistry. Unless unnaturally altered by some form of outside contamination, groundwater chemistry within the same geologic formations is routinely characterized based on the chemical makeup and balance of major cations (e.g., positively charged ions including Na+, K+, Ca++, Mg++, Fe++), anions (e.g., negatively charged ions including Cl-, HCO-3, SO=4, CO3=) and its pH. Hem (1970), for example, documents this for many "natural waters" in contact with various geologic formations. As an example, groundwater that has been in contact with carbonates or rock types cemented together with a carbonate matrix is high in calcium and bicarbonate (see Carter, Sautner, and Fiorentino samples in **Exhibits X and Y**). These figures are Stiff diagrams used in water quality assessments (see, for example, Hem, 1970). Their characteristic water

chemistry patterns provide ready visual assessment of water type and ionic balance. Anomalous water samples may be readily identified based on ionic concentrations and pattern (i.e., Ely). Maximum saturation with respect to $CaCO_3$ in such waters occurs at a pH of approximately 8.4 (Garrels and Christ, 1964). The pH of water represents the interrelated result of a number of chemical equilibria. "Most groundwaters found in the United States have pH values ranging from around 6.0 to 8.5" (Hem, 1970), with some unusual exceptions.

43. Likely causes of the high pH of the Ely well water may be Cabot's use of potassium hydroxide (also known as potassium hydrate and caustic potash [KOH]) and/or sodium hydroxide (also known as caustic soda or lye [NaOH]) as drilling additives. Both are strong alkaline chemicals that are soluble in water. Swallowing potassium hydroxide can have severe and even life-threatening effects, as noted by MedlinePlus. Ingestion may result in burns to the mouth, throat, esophagus and stomach; severe mouth, throat and abdominal pain (emphasis added); diarrhea; throat swelling shut; and a swift drop in blood pressure, which is a symptom of a shock reaction. Cabot summary sheets list components they use in their hydraulic fracture solutions. These solutions include both potassium hydroxide (in products B9 and BXL-2 listed as comprising 20 and 10 weight percent hazardous ingredient, respectively) and sodium hydroxide (in product ICI-3240; listed as comprising 4 weight percent hazardous ingredient).

44. Reference to **Exhibit W** reveals that many of the reported pH values of drill cuttings and fluids are exceptionally high – to a pH of 11.01. Elevated sodium, total dissolved solids, pH, aluminum, iron, arsenic, and strontium concentrations present in the Ely well water may, in part, stem from high pH and metal-rich contamination by pressurized drilling fluids during the drilling process (see **Exhibits I, L and W**). The widespread change in pH and natural gas concentrations in Carter Road area wells after installation of gas wells provides solid evidence for a source of

contamination from chemical additives (i.e., drilling fluid, drilling mud and/or fracking fluid). The subsurface migratory route may be fracture, fault, and wellbore interconnections (with chemical additive dispersal during hydraulic fracturing operations) (see, for example, **Exhibit M**). The driving force may be from high drilling or fracturing pressures that force contaminants to move from the wellbore through adjacent geologic formations via a pathway of least resistance.

45. The natural pH of groundwater in similar bedrock formations tapped by Carter Road area wells was found to be between about 6.1 and 7.3 (**Exhibit J**). In most natural water, the alkalinity is practically all produced by dissolved carbonate and bicarbonate ions (Hem, 1970). pH values are presented on a logarithmic scale thus, for example, Ely well water with a pH of 9.3 would reflect a pH value two orders of magnitude higher than a background pH value of 7.3. Without unnatural alteration, groundwater within the same bedrock formations should be reasonably consistent. Under natural conditions this chemical balance should remain unchanged for hundreds and tens of thousands of years. Reference to **Exhibits J and K** document that gas drilling has dramatically changed groundwater chemistry over a period of a few years. It is important to recognize that pH change serves as an indicator parameter of other geochemical changes that extend to both alteration of ionic chemistry and unnaturally high concentrations of other gas industry chemicals that range from metals to volatile organics.

46. Thus, the pH and chemistry of groundwater tapped by a number of Carter Road area wells, including the Ely well, has been unnaturally and dramatically altered by gas drilling operations (**Exhibits J and K**). It is not the drilling process itself that has caused this chemical change, but rather the unnatural addition of massive quantities of chemicals by the gas industry. Hydrogeologically, the documented groundwater chemistry now present in the Carter Road area,

especially when referencing the unnaturally altered Ely groundwater chemistry, provides evidence that contaminants have moved from gas wells to homeowner wells along joint, fault and wellbore pathways.

47. Clear site-specific documentation of available contaminant transport pathways along bedrock fractures measured nearby and documented in the field (see **Exhibit L**), is graphically illustrated using Stiff diagrams that show a change in groundwater chemistry (i.e., alteration of groundwater chemistry) from a natural calcium-bicarbonate water to a sodium-bicarbonate rich water. Thus, Cabot contaminants that are soluble (such as those that caused a widespread increase in groundwater pH), once present in groundwater, may also flow to other down gradient water supplies along interconnected joint and fault pathways. Hydraulically open and interconnected pathways are present and functioning. It is not prudent in such settings to bury metals-rich drilling waste which will be prone to leaching by infiltrating rainfall. Waste contaminants will then move within groundwater though soil horizons and fractured bedrock to contaminate homeowner wells, aquifers, streams, rivers, wetlands, ponds, lakes, and reservoirs, as has occurred in the Scott Ely well (see **Exhibit V**).

48. The large increase in pH within the bedrock aquifer, as observed at the Ely well, clearly documents water quality impact stemming from migration of deeply injected toxic contaminants (i.e., via hydraulic fracturing and drilling processes) upward into the overlying freshwater aquifer. Unnaturally high pH groundwaters and changed ionic chemistry and metals additions (i.e., Al, Fe, Na, Sr, B) in some wells, in Dimock, PA confirm hydraulic connectivity between deep gas horizons and the shallow bedrock aquifer down gradient of Cabot gas wells. A change in groundwater pH has occurred – not just in a single well-specific instance but, instead, throughout a broad area, far beyond what might be expected from a surface spill.

49. Gas industry chemicals in the Carter Road area of Dimock, PA have migrated as one or more contaminant plumes to the freshwater aquifer tapped by the Scott Ely and other wells. The May 2012 homeowner well sampling data, along with other previous chemical data, provides geochemical proof of groundwater chemistry altered by well drilling and hydraulic fracturing activities. The down hole injection of chemicals during the drilling and hydraulic fracturing processes poses a serious threat to groundwater quality, not only in the vicinity of the drilling site, but also in the entire down-gradient part of the groundwater flow system. It is evident that the process of gas well drilling, both before and after protective casings are installed, may result in unnatural alteration and contamination of pre-drilling groundwater chemistry. Although the main injection of contaminants takes place thousands of feet below the surface, groundwater flow inevitably carries them laterally and then upward into major neighboring river valleys (Exhibit V) over periods of a few hours, to years, and to hundreds of years, tailing off for possibly thousands of years.

50. The physical process of drilling gas wells represents a potentially major cause of groundwater contamination. An overlooked source and time-related aspect of groundwater contamination is that of the drilling process itself, where contamination occurs before deep gas-rich target formations are reached and hydraulically fractured. Here, pressurized metals-rich drilling fluids with elevated concentrations of pH, sodium, and TDS are forced laterally outward and upward into adjacent and overlying bedrock formations. This is one likely cause of contamination of the Scott Ely well.

51. As discussed in this affidavit, there are two possible explanations for the unnaturally elevated pH concentrations now present in portions of the Dimock aquifer, although both may contribute. One explanation involves the down hole addition of alkaline compounds during the

hydraulic fracturing process. The second explanation is independent of the hydraulic fracturing process. Under this scenario, high pH drilling muds laced with metals are forced laterally outward during the drilling process. Strong upward hydraulic gradients along with pressure exerted during the drilling process then help mix metals-rich fluids with the groundwater flow system. The water chemistry of homeowner well water may largely reflect that of the high pH drilling fluids, rather than the more expansive suite of chemicals used during the hydraulic fracturing process. Possible support for this explanation may be found in the lack of highly elevated chloride concentrations (e.g., as seen in Hawley flowback water chemistry, Exhibit W and the 1-19-12 Hawley Stiff diagram: **Exhibit Y**) in drill cuttings, drill fluid waters, and homeowner waters as might be expected if a high concentration of deep, brine-rich, connate water mixed with the freshwater aquifer. Similarly, the lack of significant concentrations of volatile organics in homeowner water may also lend support to aquifer contamination during the drilling process. Thus, it is likely that the post-drilling Ely water chemistry reflects a mixing scenario with high pH, metals-rich, drilling fluid combined with a low ionic strength calcium-bicarbonate freshwater. Beyond this, migration of contaminants from gas well site drill cuttings burial pits may also contribute to unnatural metals concentration in homeowner wells (see, for example, the red arrows that portray shallow groundwater flow vectors from the burial pit at Gesford 9 to the Scott Ely well on **Exhibit M**). Therefore, significant aquifer contamination may occur from fluid and chemical losses during the drilling process, thereby negating gas industry attempts of short-term isolation of freshwater horizons with low-durability sealant materials (i.e., cement and steel).

52. Dimock, PA represents an example location where pre-drilling groundwater chemistry has been unnaturally altered by gas industry practices. Groundwater chemistry within the Carter

Road area freshwater aquifer has been adversely impacted as a result of Cabot's natural gas drilling activity, most likely resulting from a combination of outward and upward contaminant dispersal during drilling operations and from upward transport of chemical contaminants injected down hole during hydraulic fracturing operations. The unnaturally high pH of Carter Road area groundwater (e.g., Hubert, Scott Ely, Bill Ely – see **Exhibit K**) and its large increase in pH over natural background conditions (i.e., orders of magnitude), as documented in homeowner wells, occurred within the timeframe of Cabot's gas well installations and related activities. The high pH, sodium-bicarbonate rich, Ely groundwater chemistry provides an excellent example of gas industry alteration of water chemistry. Stiff diagrams are used to illustrate representative ionic groundwater chemistry.

53. Large volumes of contaminant-laden drill cuttings and residual fluids placed in unsecured physical settings pose a significant risk to water quality and public health. Toxic and carcinogenic chemicals present within buried drill cutting materials are significant contaminant source areas that should be removed, monitored, and remediated in a manner consistent with protocols used in the investigation and remediation of hazardous waste sites.

54. Massive quantities of chemically-laced drill cutting are buried in pits at 23 or more gas well sites in Dimock, PA (Scott Ely, pers. comm.). Scott Ely was present during the operations described here. **Exhibit M** illustrates a portion of Dimock where cutting waste with fluids was buried. This industry practice is widespread in nature, probably numbering many tens of thousands or more in gas fields. Existing regulations and exemptions allow this practice that will assuredly contaminate down gradient wells, aquifers, and waterways where this has not already occurred. Each waste burial pit is a contaminant point source. Contaminants in these pits may contribute to degradation of Plaintiffs' water supplies.

55. Metal-rich drilling cuttings and residual drilling fluids pose a serious risk to fresh groundwater quality and public health. The burial practice in Dimock involved first digging waste pits ranging in size up to approximately 200 feet long by 20 feet wide by 12 feet deep. Some well sites have multiple water burial pits. The base of waste pits are in soils while others are atop bedrock. Most have membrane liners that were often ripped by excavators. The fluid/cuttings content of some of these pits, which was often black in color, was often sufficiently viscous such that it had a jelly-like consistency. While some effort was made during burial of cuttings material to keep it at a level of about two feet below the ground surface, contaminated waste material sometimes oozed out the top before soil cover was added.

56. The presence of large pits filled with toxic and radioactive material at gas well sites, including in Dimock, represent time bombs that assuredly will contaminate water resources, where this is not already occurring. Each drill cutting burial site represents a time bomb for down gradient groundwater quality and, ultimately, surface water contamination. Hydrogeologically, there is no sound justification for allowing this practice to occur. All gas well waste pits in Dimock, and elsewhere, should be located, mapped and immediately removed to secure facilities. Furthermore, hydrogeologic investigations should be undertaken proximal to and down gradient of each and every pit, the vertical and lateral extent of contaminant plumes should be determined, and cleanup efforts should be conducted. These waste pits pose great risk to water quality and human health. The practice of burying metals-rich drill cuttings material should be stopped immediately. **The presence of these waste pits (i.e., contaminant time bombs) near Plaintiffs' wells is sufficient cause alone to not needlessly expose them to these huge contaminant sources that already are, or will, release contaminants toward their wells (Exhibit M). From a health impact and humanity standpoint, it would be reprehensible to**

ask anyone to rely on a whole house water treatment system to protect their family's health knowing that huge up-gradient chemical waste pits are actively recharging their aquifers and moving toxic contaminants toward their water supplies.

57. Unfortunately, testing to date and assessments of water potability have focused largely on chemical parameters that have established MCLs, not on the hundreds of hydrofracking chemicals used, many of which are toxic and carcinogenic at low concentrations. The chemicals that cause homeowner water to have a high pH may be toxic. Review of the Ely's health history shows that they have reportedly experienced medical problems of one variety or another, including migraine headaches, dizziness, and visual disturbance particularly after consuming the water and exposure to their water in an enclosed space.

58. More likely than not the causes of the high pH of Ely water is a result of Cabot's use of potassium hydroxide (also known as potassium hydrate and caustic potash [KOH]) and/or sodium hydroxide (also known as caustic soda or lye [NaOH]) as drilling additives. Both are strong alkaline chemicals that are soluble in water. Swallowing potassium hydroxide can have severe and even life-threatening effects, as noted by MedlinePlus.

59. Ingestion may result in burns to the mouth, throat, esophagus and stomach; severe mouth, throat and ***abdominal pain*** (emphasis added); diarrhea; throat swelling shut; and a swift drop in blood pressure, which is a symptom of a shock reaction. Cabot has provided summary sheets of some of the components they use in their hydraulic fracture solutions. These solutions include both potassium hydroxide (in products B9 and BXL-2 listed as comprising 20 and 10 weight percent hazardous ingredient, respectively) and sodium hydroxide (in product ICI-3240; listed as comprising 4 weight percent hazardous ingredient). 29. The chemicals that are responsible for the extremely high pH present in this water may have already permanently impacted the health

of this family. The signs and symptoms complained of are no longer outwardly visible because they have disconnected their formerly pristine, and now irreversibly contaminated, well from their home.

60. Clearly, Cabot has not restored the quality of the water to what it was prior to gas well installation as required. Therefore, a permanent replacement water supply is needed to supply this household for the future.

61. It is my professional opinion, to a reasonable degree of hydrogeologic certainty, that to require the Ely and Hubert households to again use their degraded, high-pH, well water, with or without daily testing for all the voluminous and proprietary hydrofracking chemicals used nearby (approximately 200 meters away), would be inhumane.

62. Not only has Cabot not addressed color, pH, and other water quality parameters, but they have not conducted standard hydrogeologic testing between the Gesford wells and adversely affected homeowner wells, or any of the other gas and homeowner wells to properly assess contaminant migration.

63. As documented above, contaminants are moving between gas and homeowner wells, through an assortment of routes.

64. Monitoring wells should be installed and regularly monitored for water quality and hydrogeologic parameters so that vertical and horizontal hydraulic gradients, and coefficients of transmissivity and hydraulic conductivity can be assessed.

65. Clearly, Cabot has not restored the natural color or groundwater chemistry of the water to what it was prior to gas well installation. Also, it is obvious that if the physical pathways of groundwater flow between the Gesford gas wells and nearby homeowner wells is able to transport colloidal-

sized particles, then untold numbers and types of contaminants can also move with the groundwater flow system to homeowner wells.

66. This water is not fit to drink and should also not be used for bathing. Dimock homeowners in addition to the Elys, prior to settling their claims in this case, report assorted medical problems occurred after installation of the Gesford wells and coincident with the visual change in the quality of their water, including headaches, stomach cramps, and blotches on their skin.

67. Given all of the foregoing, it is my professional opinion as an experienced hydrogeologist that, to a reasonable degree of professional certainty, the defensive claims of Cabot Gas & Oil Corporation in their motion papers and expressed through their industry scientists regarding the absence of harm in contaminating the Ely-Hubert water supplies and in the alternative the effectiveness of their proffered water treatment systems, are implausible at best, and that the remaining affected Plaintiffs' claim should be presented to a jury of their peers, and not swept under the rug, for the Plaintiffs and as a matter of public policy.

68. This report is based on information available to me at this time. Should additional information become available, I reserve the right to determine the impact, if any, of the new information on my opinions and conclusions and to modify or supplement this report if necessary.

Dated: June 15, 2013

Respectfully submitted,

Paul A. Rubin

Paul A. Rubin

Rubin

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EDUCATION:

M.A. - Geology, May 1983, State University of New York at New Paltz. Major fields of study: Hydrogeology, Water Quality and Pollution, Structural Geology, Photogeologic Interpretation. Thesis topic: *Hydrogeology and Structure of the Shawangunk Mountains, Ulster County, NY.*
B.A. - Anthropology, minor Geology, May 1977. State University of New York at Albany.

SPECIAL SKILLS:

Environmental Protection; Hydrologic and Geologic Characterizations; Land Use Planning & Characterizations; SEQRA reviews; Expert Testimony and Litigation Background; Surface Water and Groundwater Quality Evaluations; Sediment Transport; Evaluation of Remedial Technologies; Geotechnical Assessments; Hydrologic Investigations; Aquifer Testing and Analysis; Karst Hydrology; Rosgen Stream Analyses; Flood Return Analyses; GIS Map Making and Analyses; Photogrammetric Analyses; Affidavit and Report Preparation; Land Protection; Educator; Public Speaking; Public Relations; Research Skills; Strategy Development; Leadership.

EXPERIENCE:
HYDROLOGIST/ HYDROGEOLOGIST:

1993 - Present

Independent Consultant. Stone Ridge, New York. Consulting firm: *HydroQuest.* Provide hydrologic, geologic and land use technical consulting services to environmental groups, Towns, business associations, law firms, and individuals. Assist groups in identifying issues and developing strategies designed to protect groundwater and surface water resources, community character, and wildlife habitat.

***HydroQuest* work includes SEQRA reviews, review and fatal flaw analyses of consultant reports and environmental impact statements (EISs); environmental scoping report preparation; direction and oversight of heavy equipment operators for field excavation work for well placements, contaminant characterization, and geologic investigations; technical coordination of scientific case development for environmental groups and attorneys; field characterizations; stream and wetland evaluations; geotechnical analyses; hydrologic and geologic mapping; water quality assessments; watershed delineations; viewshed analyses; slope analyses; aquifer analyses; hydrogeologic analyses; regulatory assessments; GIS map preparation; public presentations; technical presentations to judges; coordination work with attorneys and Technical Committees; direction and coordination of sub-contract work as needed; strategy development; panel member at Town meetings with legislators; press interactions; report and affidavit preparation. Recently authored many major reports and affidavits on gas drilling & hydraulic fracturing (see supplemental resume).**

Recent project work examples include oversight and analysis of well field pumping tests (for multiple groups including NRDC, NYPIRG, Riverkeeper, and Trout Unlimited) designed to assess impacts on groundwater and surface water stemming from a planned large-scale Catskill Mountain resort; assessment of a town's water quality problem with corrective recommendations; initial hydrogeologic assessment of a spring water source being considered for bottled water use; hydrogeologic-aquifer analysis of a groundwater supply proposed for a Shawangunk Ridge retreat center; SEQRA assessments; and technical presentations and testimony before administrative law judges.

KARST HYDROLOGIST

Howe Caverns, Inc. Cobleskill, New York. 2nd largest natural tourist attraction in NYS

2004 - April 2007 **Conducted hydrologic and geologic research, produced professional GIS maps and figures, developed educational programs and materials, developed new tourist route, trained guides, provided land use assessments and recommendations, advised the Board of Directors on land use concerns including potential water quality degradation and potential blast-related impacts to cave. Developed and proposed revenue generating strategies. Coordinated with outside educational institutions, professional geologists, learning institutions, and scout groups. Formerly worked in this position half-time prior to change in ownership.**

INSTRUCTOR:

Jan. 2001- Dec. 2004 **SUNY Ulster, Stone Ridge, New York.**
Taught ArcGIS, Environmental Geology, Geology, Hydrology, Geography, and Crime Analysis. Coordinator of a Geographic Information Systems certificate program. Developed, obtained, and completed a NYSDEC grant to assess assorted hydrologic and environmental aspects of the Black Creek watershed in Ulster County. Supervision and oversight of numerous professional adult "students", directed GIS-based technical presentations, and coordinated and produced grant products.

College of the Atlantic, Bar Harbor, Maine.
Taught a two week graduate level summer field hydrology and environmental science course for several years, including Rosgen stream assessment.

HYDROLOGIST:

New York City Department of Environmental Protection (NYC DEP), Division of Drinking Water Quality Control, Shokan, New York.

April 1993- Jan. 2001 **Conducted research and field studies designed to assess the water quality of watersheds. Responsible for directing geologic research designed to assess the sources, geomorphic context and best management practices (BMPs) related to sediments causing turbidity water pollution problems. Hydrologic and geologic work included geologic mapping of glacial sediments, field evaluation of stream channel armoring, morphologic characterization of stream channels (including Rosgen analyses), bedload transport studies, assessment of critical shear stresses, particle size analysis, stream gauging, water quality sampling and trend analysis, chemical and sediment loading calculations, graphic production, report preparation and technical presentations. Assisted other governmental divisions in evaluating lands for possible purchase, conducted geotechnical assessments of structurally unstable stream reaches, evaluated BMP designs. Supervised several Research Assistants.**

RESEARCH SCIENTIST:

Martin Marietta Energy Systems, Inc. April 1993 under contract with the U.S. Dept. of Energy; Oak Ridge National Lab; Environmental Sciences Division, Oak Ridge, TN.

Aug. 1991- April 1993 **Responsible for hydrogeologic evaluation of groundwater issues (e.g., characterization, monitoring network setup, data analysis, remedial design evaluation) at multiple Oak Ridge Reservation hazardous waste sites. Developed and documented conceptual model of carbonate and shallow storm flow systems comprising pathways of rapid contaminant transport. Work also involved characterization of hydrologic and geochemical trends**

RESEARCH SCIENTIST continued:

and thermal infrared photo analysis. Presented results of research at conferences, as well as to DOE management and State and Federal officials. ***Served in a Resource Management Organization as the hydrologic lead for the Environmental Sciences Division.***

HYDROGEOLOGIST:

New York State Attorney General's Office; Environmental Protection Bureau, Albany, New York.

Feb. 1983- Aug. 1991 **Responsible for the design, protocols, coordination, implementation, evaluation, characterization and remediation of many major water and soil contamination sites throughout New York State (e.g., Love Canal, Superfund sites). Designed, performed and supervised chemical field sampling at hazardous waste sites. Evaluated geotechnical and chemical data sets.**

Primary responsibilities included coordination of multiple companies along with their respective legal and scientific consultants. Worked with all parties involved to produce test plans and consent decrees to facilitate site remediation. Responsible for the management of the testing, site characterization and technical assessment. Worked with attorneys on summary judgment motions, complaints, trial preparation and depositions. Attorney General's spokesperson at public meetings. Expert witness at SEQRA hearings. Testimony given before the Assembly Standing Committee on Environmental Conservation and Grand Jury. Worked with DOL staff and attorneys to develop office initiatives (e.g., Racketeering; bottled water contaminants). Initiation, development and drafting of legislation.

Supervision of personnel: expert witnesses, consultants, research assistants, interns. Responsible for selection, job descriptions, work schedules, and products.

HYDROGEOLOGIST:

Stone & Webster Engineering Corp., Geotechnical Division, Boston, Massachusetts.

Oct. 1981- Feb. 1983 **Directly responsible for the planning, preparation, execution, and analysis of pumping tests and a fluid sampling program designed to investigate deep basin groundwater characteristics for the siting of a nuclear waste repository within the Permian Basin of the Texas panhandle. Planned, managed, coordinated, directed, and provided oversight of field operations of a multi-million dollar project. Sub-contractors included Halliburton, Schlumberger, and others.**

ACTIVITIES:

Hiking, geologic and hydrologic research, and exploration. Former Captain: Albany-Schoharie County Cave Rescue Team. Made a Fellow of the National Speleological Society in recognition of karst research and water resource protection.

PUBLICATIONS & REPORTS **Over 50 technical publications and over 100 reports and affidavits, many for private clients, environmental groups, towns, and law firms. Projects include land, wetland, water quality, and species protection; aquifer and watershed characterization; mine proposals; development proposals; contaminant assessments; stream hydrology grant work; and flood risk. Some reports are confidential. Leader of geology conference field trips for groups including the New York State Geological Association, the American Institute of Professional Geologists, the Hudson-Mohawk Professional Geologists' Association, the National Ground Water Association, the National Speleological Society, and the International Association of Geochemists and Cosmochemists.**

ADDENDUM - SELECTED PUBLICATIONS

SELECTED PUBLICATIONS FROM PROFESSIONAL AND PERSONAL RESEARCH

Rubin, P.A., 2009, ***Geological Evolution of the Cobleskill Plateau; New York State, USA,*** in Veni et al. (eds), Proceedings of the Speleogenesis Symposium of the 15th International Congress of Speleology (joint National Speleological Society & Union Internationale de Speleologie); Symposium: Speleogenesis in Regional Geological Evolution and its Role in Karst Hydrogeology and Geomorphology, Kerrville, Texas. Proceedings, Volume 2, Symposia Part 2, pages 972-978 (published July 2009).

Palmer, A.N. and Rubin, P.A., 2007, ***Karst of the Silurian-Devonian Carbonates in Eastern New York State, with emphasis on the Cobleskill Plateau***. Guidebook for the Hudson-Mohawk Professional Geologists' Association Spring 2007 Field Trip, *"Carbonate Geology of the Howes Cave Area, Schoharie County, New York"*, p. 17-35, Trip coleader with Arthur Palmer (April 28, 2007).

Rubin, P.A., Burmeister, K.C. and Folsom, M., 2006, ***Karst Resource Management: groundwater protection and developmental considerations in the Kingston-Rosendale aquifer system***; Ulster County, N.Y., Poster Presentation at the 2005 National Cave and Karst Management Symposium. Report prepared for Scenic Hudson.

Stokowski, S., Rubin, P.A. and Guenther, B., 2006, ***History of resource management: conflict and resolution, Howes Cave, N.Y.***, in Rea, G.T., (ed), Proceedings of the 2005 National Cave and Karst Management Symposium.

Rubin, P.A and Stokowski, S., 2004, ***Karst, Caves, and Quarries***. Guidebook paper for ***the*** American Institute of Professional Geologists (AIPG), Annual Meeting. Field trip co-leader.

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Rubin, P.A., Adickes, D.M., Cunningham, T., Davidson, D., Hurld, J. Kiyan, J.R., Preuss, P., Ramsay, W., Schultz, B. and Washington, George, 2004, ***Application of GIS technology to assess visual impacts of development: Shawangunk Ridge case study, southeastern NYS***. Abstracts Northeast Natural History Conference VIII. N.Y. State Museum Circular 66: p. 52-53.

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Kiyan, J.R., Washington, G., and Rubin, P.A., 2004, ***GIS visual impact analysis of a proposed housing development below Minnewaska State Park Preserve in the Shawangunk Mountains of the Mid-Hudson Valley in New York State***. Abstracts Northeast Natural History Conference VIII. N.Y. State Museum Circular 66: p. 47.

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Palmer, A.N., Rubin, P.A., Palmer, M.V., Engel, T.D., and Morgan, B., 2003, ***Karst of the Schoharie Valley, New York.*** Guidebook for the New York State Geological Association Diamond Jubilee Field Conference (75th Annual Meeting), p. 141-176, Trip coleader.

Rubin, P.A., Morgan, B., and Palmer, A.N., 2003, ***Howe Caverns resource protection: hydrology and land-use analysis; Schoharie County***, New York State. Abs. Northeastern Science Foundation Silver Jubilee Anniversary Symposium, Proceedings volume, p. 25-26.

Rubin, P.A., Hubsch, R., Albrechtsen, C.A., Black, G., Folsom, M., Keller, J., Morgan, B., Ortega, A., Rodden, M., Schultz, B., Terzella, D., and Washington, G., 2003, ***Watershed management and protection planning based delineation of critical environmental areas via GIS analysis.*** Abs. Northeastern Science Foundation Silver Jubilee Anniversary Symposium, Proceedings volume, p. 13.

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Rubin, P.A., Engel, T., Nardacci, M. and Morgan, B.E., 2002, ***Geology and paleogeography of Mount Desert Island and surrounding area, Maine.*** Guidebook paper National Speleological Society annual meeting, Camden, Maine, p. 47-91, Trip leader.

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Morgan, B., Albrechtsen, C., Dido, R., Hubsch, R., Rubin, P.A., Sheeley, D., Skerritt, F. and Vaeth, L., 2002, ***Development of a GIS-based land-use coverage: Black Creek Watershed, Southeastern NYS.*** Abs. Northeast Natural History Conference VII. N.Y. State Museum Circular 64: p. 50-51.

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Most HydroQuest reports, figures, and Fact Sheets referenced at assorted web pages below may be viewed at: http://hydroquest.com/Hydrofracking/

Paul Rubin/HydroQuest Gas Drilling Related Reports, Presentations, Affidavits, Meetings & Interviews:

Oct. 2011 to Present – Advancing hydrogeologic and chemical characterization of hydrofracturing related groundwater contamination cases in support of active, high-profile, litigation with a number of law firms. Work involves site field work, groundwater sampling, hydrogeologic characterization, mediation sessions, technical guidance, and affidavit and report preparation for PA and NYS cases. Many settlement agreements have been completed in Dimock, PA cases.

March 13, 2013 – Expert panelist at conference: Corporate Interference with Science & Health. Presentation title: *Contaminant flow paths from gas wells to homeowner wells, aquifers, rivers and reservoirs. Can regulations adequately protect freshwater resources?* Conference location – New York City.

Feb. 19, 2013 – Brine dispersal Freedom of Information Law (FOIL) example request letter. Letter includes chemical and hydrologic rationale to not disperse gas industry wastewater (e.g., flowback water) and brines on roadways (i.e., contamination of waterways and aquifers). Detailed information requests contained in letter constructed for use by individuals and groups who seek to determine if gas industry chemicals are being used.

Feb. 15, 2013 – Letter to Muskingum Watershed Conservancy District regarding hydrologic issues stemming from planned gas drilling that will result in water quality, recreation and reservoir development degradation in violation of deed restrictions. Written for Southeast Ohio Alliance to Save Our Water.

Nov. 12, 2012, Jan. 25, 2013 and Feb. 26, 2013 – Constructed three affidavits detailing hydrologic problems associated with **selling Corning aquifer water to the gas industry** for use as hydraulic fracturing water for a location in New York State. For Sierra Club, other environmental groups, and individuals. Affidavits in opposition to Respondents' motion to dismiss and/or for summary judgment relative to the sale, distribution, and planned use of potable waters of New York State as naturally occurs within a primary unconsolidated aquifer.

Jan. 11, 2013 – Constructed a **technical affidavit** providing the only hydrologic and empirically based rationale for **setback distances** from gas well arrays. Provided to the State of New York on behalf of Center for Sustainable Rural Communities of Richmondville, New York to document that the NYS revised hydraulic fracturing regulations A) fail to acknowledge scientific rationale relative to setback distances provided to NYSDEC by HydroQuest both within and after the dSGEIS comment period, B) fail to use "*facts and science*" to develop setback distances, and C) seek to adopt setback distances irrespective of any empirical scientific basis whatsoever. Fifteen pages plus 5 exhibits.

October 17, 2012 – Report preparation: *Hydrogeologic Concerns Regarding Hydraulic Fracturing within the Muskingum River Watershed in Eastern Ohio with Justification & Recommendations in Support of a Drilling Moratorium within Reservoir Watersheds and Statewide Legislation Banning Hydraulic Fracturing* for South-east Ohio Alliance to Save Our Water; 42 pages with 10 figures (includes earthquake probability analyses). Technical guidance provided on an ongoing basis.

September 15, 2012 – Report preparation: *Bedrock Geology of the Marcellus and Utica Shales in the Town of Marbletown, Southeastern New York State with Justification & Recommendations in Support of Legislation Banning Hydraulic Fracturing* for Stand for Land; 15 pages with figures including GIS maps.

September 6, 2012 – Invited speaker before full Dutchess County Legislature, NYS. Topic: *Hydraulic Fracturing Brine Prohibition Act.* Written technical supportive statement provided in advance on 8-17-12.

August 14, 2012 – Fact Sheet constructed. Topic: *Key Reasons to Ban Hydraulic Fracturing in NYS*. Provided to NYS DEC and NYS Governor's office by HydroQuest in support of postponing hydraulic fracturing decision in NYS (2 pages with numerous references).

August 13, 2012 – Hydrogeologist educator at meeting with NYS Governor Cuomo's executive staff (Robert Hallman, NYS Deputy Secretary of Environment, Basil Seggos, NYS Assistant Deputy Secretary of Environment and DEC official) to discuss the independent science on hydrofracking in support of a ban on hydraulic fracturing in NYS (hosted by Grassroots Environmental Education at the Capitol in Albany). Fact Sheet and hydrofracking related material provided.

June 26, 2012 – Report preparation: *Hydrogeologic Implications of Using Partially Treated Landfill Leachate in the Hydraulic Fracturing Process for the Delaware Riverkeeper Network*; Report addresses a first attempt by the gas industry to use partially treated landfill leachate as fracking water in PA. This would be an extremely poor precedent that would increase contaminant loading to regional aquifer flow systems; 14 pages.

June 12, 2012 – Report preparation: *Hydrologic and Environmental Rationale to Bury Gas Pipelines using Horizontal Directional Drilling Technology at Stream and River Crossings* for the Delaware Riverkeeper Network; Transcontinental Gas Pipeline Company, LLC - Brandywine Creek case example used; 14 pages plus 2 figures and flood return analysis.

May 30, 2012 – Panel Member/Speaker in PA. Topic: *PA House Bill No. 1950 (Act 13) – Hydrogeologic Considerations with Implications for Degradation of Groundwater and Surface Water Quality in Berks Co., PA.*

April 25, 2012 – Testified before the NYS Senate in Albany, NY. Topic: *Hydrogeologic Justification for Banning Hydraulic Fracturing throughout New York State and the Delaware River Basin* (Testimony and report provided at the Senate Democratic Conference Public Hearing on Fracking Legislation in Albany, New York by HydroQuest and Mid-Hudson Geosciences)

April 19, 2012 – Panel Member/Speaker in PA. Topic: *PA House Bill No. 1950 (Act 13) – Hydrogeologic Considerations with Implications for Degradation of Groundwater and Surface Water Quality in the Newark Basin, Bucks Co., PA.*

April 17, 2012 – Testified before the Ulster County NY Legislature on adverse contaminant transport issues related to proposed spreading of hydraulic fracturing derived brine wastes on roads. Testimony and official statement provided in support of legislation designed to ban brine dispersal to groundwater aquifers and waterways.

January 23, 2012 - Speaker at Press Conference. Topic: *Fracking, Aquifers and Earthquakes are Connected.* Conference held in Albany, NY in Legislative Office Bldg. press room before multiple TV stations and other press entities. Open discussion, Q&A, and initial presentation shared with Dr. Arthur N. Palmer, hydrologist. Press conference sponsored by Schoharie Valley Watch and Sustainable Otsego. This press conference preceded a major anti-fracking rally in the capital area that called for a legislative ban on hydraulic fracturing.

January 23, 2012 – Assemblyman Office Meeting. Private meeting between Paul Rubin and Dr. Arthur Palmer and representatives of Assemblyman Robert K. Sweeney's [Chairman of the New York State Assembly Standing Committee on Environmental Conservation] office. Sweeney requested the meeting to address questions they had relating to local and regional groundwater flow as related to transport of hydrofracking contaminants.

January 17, 2012 – Report completed on the *Planned Quarry Road Mine – Karst Hydrology & Gas Drilling Concerns; Perryville, New York* for the Sullivan Citizens Alliance (Chittenango, NY). Report details concerns relative to the karst hydrology and potential environmental impacts associated with a proposed Oot Quarry application (19 pages plus 7 figures with GIS maps).

January 10, 2012 - *Aquifer & Karst Protection Considerations in Schoharie and Other New York State Counties* (Comments on the NYS High-Volume Hydraulic Fracturing 2011 revised draft SGEIS). Technical report that addresses the need for tracer addition to fracking fluids, vulnerability of karst terrains, limitations of well bore sealant materials, aquifer protection and other issues. In addition, analyses are provided in support of an empirically-based 2,100 foot setback distance from well arrays, the high probability of well bore sealant material failure from earthquake events, and a flood return analysis supporting no well pads within 500-year floodplains. Documentation was provided in support of NYSDEC withdrawing their revised draft SGEIS on gas drilling regulations. [Full report, related figures and analyses

may be viewed at: http://hydroquest.com/Schoharie/]

December 2011 – Contributor to *Protecting Pennsylvania Communities from the Shale Rush: A Handbook for Local Residents and Officials* by Delaware Riverkeeper Network, 76 pages.

December 6, 2011 – Speaker at Press Event. Topic: *Technical Justification in Support of Requiring Cabot to Immediately Resume Water Deliveries to Adversely Impacted Residents of Dimock, PA* [Public statement made at a press event held in Dimock, PA on Dec. 6, 2011 with associated 5-page technical statement]

November 23, 2011 – Authored an affidavit in support of Dimock, PA Petitioners' Petition for Supersedeas requesting that the Pennsylvania Environmental Hearing Board restore the *status quo* to conditions prior to the Pennsylvania DEP's determination that Cabot Oil and Gas Corporation may cease supplying affected residents of Dimock, PA with temporary potable water due to Cabot's compliance with paragraph 6 of the December 15, 2010 Consent Order and Settlement Agreement, Section 208 of the Oil and Gas Act and related environmental regulations. The affidavit addresses geologic and hydrogeologic factors governing water quality degradation of homeowner wells. The affidavit is Exhibit J of a legal petition filed by the law firm of Napoli Bern Ripka Shkolnik & Associates, LLP. In docket 2011165. Exhibit J.

November 17, 2011 – Presented a Power Point presentation in West Virginia at a Special Meeting of the County Commission before commissioners, town and planning board members, the public, and the press titled: *Hydrofracking, Karst Vulnerability and Degradation of Water Resources*. The final recommendation provided was to enact a temporary moratorium to be followed by a permanent statewide ban on hydraulic fracturing.

November 15, 2011 – Drafted a 10-page report on behalf of Damascus Citizens for Sustainability addressed to the Division of Municipal and Residual Waste, Bureau of Waste Management's Special Conditions General Permit WMGR064 addressing hydrologic issues associated with *Natural Gas Brine Dispersal on Roadways and the Risk of Surface and Groundwater Contamination*.

October 15, 2011 – Led an all day field course addressing *Hydrology & Hydrofracking* for The Heldeberg Workshop based near Albany, New York. The course was designed for teacher development and 8 credit hours of in-service credit. Abridged course description: A hands-on field look at aquifers that supply our wells and streams with pure water. While touring local nature preserves, take a close look at the major aquifer types (unconsolidated, fractured bedrock, karst) and join in discussions of how groundwater and contaminants move in them, how freshwater aquifers are physically separated from deep, saline, waters and how they provide the sustained base flow to our streams. Hydraulic fracturing (hydrofracking) will be extensively discussed, inclusive of means of methane and contaminant movement from gas-rich shale beds to explosive flares at kitchen taps.

October 2011 - January 2012 – Developing an affidavit for a legal challenge designed to force the Delaware River Basin Commission (DRBC) and the Army Corps of Engineers to follow federal environmental laws and do a comprehensive environmental impact study before they issue their draft gas rules as final and before any drilling starts. The affidavit will address numerous hydrogeologic/technical issues and will detail likely "irreparable harm" to freshwater aquifers and streams should gas drilling under the proposed regulations be advanced. The affidavit will be filed in federal court by the Delaware Riverkeeper Network.

October 6, 2011 – Presented expert testimony to the New York State Assembly Standing Committee on Environmental Conservation in Albany, NY. Testimony subject: *Protection of Freshwater Aquifers: Hydrogeologic and Seismic Threshold Requirements*. Received a personal thank you letter from Robert Sweeney, Chairman of the Assembly ECC.

September 8, 2011 – Freedom from Fracking plenary conference speaker for the Delaware Riverkeeper Network at a conference in Philadelphia, PA called Shale Outrage. Plenary talk topic: *Gas Wells & Hydraulic Fracturing: A Means to Long-Term Aquifer Degradation*.

September 8, 2011 – Freedom from Fracking workshop conference presenter for the Delaware Riverkeeper Network at a conference in Philadelphia, PA called Shale Outrage. Talk and workshop topic: *Our Aquifers, Our Drinking Water: Casualties of Gas Development*.

September 6, 2011 – Panel Presenter: Provided expert testimony before the Citizens Marcellus Shale Commission (Southeastern Pennsylvania Hearing in Philadelphia) detailing hydrogeologic thresholds that must be met in order to safeguard freshwater aquifers in perpetuity.

September 2011 – Completed a second two-sided Environmental Fact Sheet for the Delaware Riverkeeper summarizing 1) key short and long-term risks to groundwater quality in Delaware River Basin aquifers stemming from gas drilling in a seismically active region, and 2) a recommended preliminary hydrologic test procedure designed to reduce contamination of homeowner wells proximal to proposed gas wells. Fact Sheet title: *What the experts have to say about ... Natural Gas Drilling, Seismic Risk & Aquifer Degradation.*

July 8, 2011 - Preparation of a report for the Sierra Club (Pennsylvania Chapter) on the Underground Injection Control Permits Issued by the Environmental Protection Agency for Bittinger Wells #1 and #4 for disposal of fracking-related waste. This work entailed review of technical material, preparation of graphics, and collaboration with Katherine Beinkafner (Mid-Hudson Geosciences). The report and thirteen related graphics may be viewed at: http://hydroquest.com/Bittinger/.

June 8, 2011 – Presentation at a special joint meeting of the Town of Sullivan Town Council, Zoning Board of Appeals, and Planning Board in Chittenango, New York (Madison County). Power Point presentation title: *Hydrologic Considerations Relative to Mining in a Karst Terrain & Contaminant Risks to Fresh Groundwater Supplies Stemming from Hydraulic Fracturing.*

June 2011 – Constructed a two-sided Environmental Fact Sheet for the Delaware Riverkeeper summarizing key long-term risks to groundwater quality in Delaware River Basin aquifers, as well as other aquifers throughout the world, stemming from gas drilling. Fact Sheet title: *What the experts have to say about ... Natural Gas Drilling & Aquifer Protection.* The Aquifer Protection Expert Fact Sheet may be viewed and downloaded at: http://hydroquest.com/DRBCfigures/.

April 9, 2011 - Prepared comments on the DRBC draft Natural Gas Development Regulations; Article 7 of Part III – Basin Regulations on behalf of the Delaware Riverkeeper Network, 72 pages with an additional 21 figures. The report and related figures, plus a related summary June 2011 Aquifer Protection Expert Fact Sheet, may be viewed and downloaded at: http://hydroquest.com/DRBCfigures/.

April 2, 2011 - Interviewed by Sabrina Artel for a radio talk show. This is part of her Frack Talk - The Marcellus Shale Water Project. Items discussed included flaws in current gas drilling technology that will lead to widespread groundwater contamination in gas fields, failure mechanisms in "*protective*" cement sheaths and steel casing, life of production wells vs. life of aquifers, and seismic risk in the Delaware River Basin.

February 18, 2011 – Delivered a Power Point presentation for Delaware Riverkeeper as part of a day-long webcast workshop on Translating the DRBC Gas Rules. Talk title: *How the draft rules address hydrogeologic impacts of gas development.*

February 10, 2011 - Representative of several Towns (Highland, Lumberland et al.) at a special work session of the Upper Delaware Council's project review committee. Assisted the UDC in their review of the DRBC's Draft Natural Gas Development Regulations in Narrowsburg, New York.

November 15, 2010 – Prepared a report on behalf of the Delaware Riverkeeper Network and the Damascus Citizens for the Sustainability for the Delaware River Basin Commission Consolidated Administrative Hearing on Grandfathered Exploration Wells. (22 pages, plus 10 figures and 3 addenda). The report and 10 related figures may be viewed and downloaded at: http://hydroquest.com/Riverkeeper/.

September 11, 2010 – Provided comments on the Scope of the Proposed EPA Study of Hydraulic Fracturing. Prepared on behalf of Otsego 2000; 14 pages with 7 figures. The report and figures may be viewed and downloaded from the Otsego 2000 web page: [http://63.134.196.109/documents/HydroQuestEPAComments9-11-10withfigures.pdf].

December 30, 2009 - Provided significant geologic and hydrologic input into a 45-page letter authored by Zarin & Steinmetz, attorneys for Otsego 2000. The letter provides extensive comments on the Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Program: Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low Permeability Gas Resources ("DSGEIS"). The letter may be viewed and downloaded at: http://63.134.196.109/documents/DSGEISCommentLtr123009.pdf.

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I, PAUL RUBIN, being duly sworn, deposes and says that:

1. I am a hydrogeologist and hydrologist with thirty years of professional experience. I earned a B.A. degree from the State University of New York at Albany in 1977 and an M.A. degree in geology with a specialty in hydrogeology from the State University of New York at New Paltz in May, 1983. My professional experience includes work conducted for the New York State Attorney General's Office (Environmental Protection Bureau), Oak Ridge National Laboratory (Environmental Sciences Division), the New York City Department of Environmental Protection, and as an independent environmental consultant as President of HydroQuest. My educational background and professional experience are more fully set forth in my Curriculum Vitae, attached as **Exhibit 1**.

2. Within the broad field of hydrology, I have specialized expertise in both surface water and groundwater hydrology. Beyond this, I have specialized expertise in karst hydrogeology. I have conducted detailed assessments of streams, wetlands, watersheds, and aquifers for professional characterizations, for clients and as part of my own personal research. I have authored numerous reports and affidavits related to this work and have made presentations to judges, juries, and the assembly. In addition, I have published papers and led all day field trips relating to this work at professional conferences.

3. More recently, I have been called upon by a number of environmental groups to address hydrogeologic and environmental issues associated with hydraulic fracturing. A synopsis of this work is attached as **Exhibit 2**. This work has been delivered in the form of various reports, presentations, and fact sheets. In addition, as a knowledgeable and concerned hydrogeologist, I have independently constructed and delivered testimony on the dangers of hydraulic fracturing to our freshwater aquifers. I delivered testimony to the Citizens Marcellus Shale Commission in Philadelphia, PA on September 6, 2011 and to the New York State Assembly Standing Committee on Environmental Conservation in Albany, New York on October 6, 2011.

4. This affidavit is in support of the Petitioners' supesedeas and temporary supersedeas petitions before the Board. The Petitioners are likely to suffer "immediate and irreparable injury" to their persons if Cabot Oil and Gas Corporation ("Cabot") is allowed to discontinue deliveries of fresh bulk and bottled water to the Petitioners.

5. Water sampling data from 2010 and 2011 demonstrate that the Petitioners' well water supplies continue to detect elevated levels of aluminum, barium, beryllium, iron, manganese and toluene. Sampling data also detected non-naturally occurring chemicals associated with fracking such as bis (2-Ethylhexyl) adipate, bis (2-Ethylhexyl) phthalate and ethylene glycol. See sampling data annexed hereto as **Exhibit 3**.

6. The consumption of water with such constituents poses a threat to human health and the Petitioners should not be subjected to drinking such water.

7. On October 28, 2011, I collected water from the well of one of the Petitioners, Nolen Scott Ely ("Mr. Ely"), for microscopic observation and analysis. Two weeks after collection, Mr. Ely's water was still turbid, thereby indicating the presence of extremely fine-grained colloidal clay entrained in the water. The source of this material is probably from a combination of glacial till that overlies bedrock in the area and drilling mud forced into bedrock fractures during well construction. Prior to construction of Gesford wells 3 and 9, Mr. Ely's well was clear since it was drilled in the 2004-2005 time period. The current turbid water is not the natural condition of Mr. Ely's water prior to construction of nearby gas wells.

8. Examination of the bedrock quarry along Carter Road revealed that the bedrock is extensively fractured and faulted. **Exhibit 4** depicts the prominent north-south fracture/joint orientation, with a less prominent east-west fracture orientation that connects major north-south fractures. In addition to interconnected fractures, the Carter Road Quarry reveals that the area has been faulted on at least two occasions (**Exhibit 5**). Fracture and fault plane interconnections provide the likely sediment transport pathway between the Gesford gas wells and Mr. Ely's well.

9. On November 22, 2011, I collected water samples from the Sautner well, Carter well and Mr. Ely's well. Annexed as **Exhibit 6** is a photograph of their conditions at the time of sampling. Although the Saunter water appeared clear on this date it been reported that, at times, the water clarity decreases. Both the Carter well and Mr. Ely's well exhibit unnatural color relative to the normal, clear, groundwater that was present for years before Cabot installed gas wells nearby. The color of Mr. Ely's water depicted in Exhibit 4 is equivalent to Munsell color 7.5 YR 5/ 4 - brown. The laboratory will soon provide a standard assessment of color, not that one is needed when looking at Exhibit 4. Clearly, Cabot has not restored the natural color of the water to what it was prior to gas well installation. Also, it is obvious that if the physical condition of groundwater flow between the Gesford gas wells and Mr. Ely's well is able to transport colloidal-sized particles, then untold numbers and types of contaminants can also move with the groundwater flow system to Mr. Ely's well. This water is NOT fit to drink and should not be used for bathing, at least until the cause of the greatly elevated pH discussed below is known. Water deliveries should be continued.

10. Mr. Ely's well serves as one Dimock homeowner well example, among others, of degraded water quality. Beyond the turbid water present in Mr. Ely's well, another outstanding water quality parameter of note is the well water pH that has been documented on a number of occasions as being in the pH 9.5 range. This amazingly alkaline water is far from normal and, like the water quality parameter "color", falls outside recommended drinking water quality standards. Because pH is a logarithmic scale, a pH of 9.5 is two orders of magnitude,

or 100 times, higher than a more normal pH of 7.5. Something is VERY wrong with this groundwater. It should NOT be ingested. One or more chemicals must be causing this elevated pH value. Unfortunately, testing to date has focused largely on a small number of chemical parameters that have Maximum Contaminant Levels (MCLs), but not on the hundreds of hydrofracking chemicals used, many of which are toxic and carcinogenic. The entire Ely family has experienced medical problems of one variety or another, including blotches on their skin. Whatever unknown chemicals are responsible for the extremely high pH present in this water may have already permanently impacted the health of this family. The medical problems of the Ely family are no longer outwardly visible because Mr. Ely has disconnected his formerly pristine well from his home. Clearly, Cabot has not restored the quality of the water to what it was prior to gas well installation. In my professional opinion, to stop water deliveries and require the Ely family, and other adversely impacted families, to start using degraded water, untested for all the voluminous hydrofracking chemicals used nearby (approximately 200 meters away), would be inhumane and would not meet the spirit of the current regulations. Beyond this, to do so would potentially incur great legal and financial risk to the Commonwealth.

11. Not only has Cabot not addressed color, pH, and other water quality parameters, but they have not conducted standard hydrogeologic testing between the Gesford wells and Mr. Ely's well, or any of the other gas and homeowner wells as well to assess contaminant migration. Contaminants are moving between gas and homeowner wells, potentially through an assortment of routes. Perhaps some contaminant movement has occurred from the ground surface at the gas wellheads down gradient to Mr. Ely's well following chemical losses associated with sloppy well pad operations. As such, monitoring wells should installed and monitored for water quality and hydrogeologic parameters so that vertical and horizontal hydraulic gradients, and coefficients of transmissivity and hydraulic conductivity can be assessed.

12. To stop water deliveries also puts numerous other homeowners at risk along Carter Road. Seeing the discolored and high pH waters along Carter Road yesterday was unfortunate. However, in my mind this paled when compared to a conversation I had with Pat Farnelli. I don't believe that Ms. Farnelli receives water from Cabot. Her domestic well is literally surrounded by gas wells. There is little doubt that the footprint of both the well verticals and the many elongate horizontal projections, when plotted, will appear as an extensive network close to her and others. Ms. Farnelli related that she and her five children bath in their well water. All have developed rashes. These are five children who are potentially being exposed to hundreds of hydrofracking related chemicals on an ongoing, daily, basis. Ms. Farnelli and any other Carter Road homeowners in a similar situation should be immediately added to existing water deliveries until such time as extensive groundwater testing for all hydrofracking chemicals has been conducted. This is an intolerable and dangerous situation.

13. The extensive joint/fracture network present in the Carter Road area is significant from both a gas production standpoint and in terms of an interconnected fracture network capable of serving as contaminant transport pathways. Based on the prominent north-south and east-west fracture orientations (Exhibit 4) in the area, the overall north-south alignment of many adversely impacted wells, and the generally southerly sloping terrain in much of the Carter Road area, it is not surprising that Bill Ely's well exhibits some of the highest methane levels. Essentially, Bill Ely's well, with a depth of several hundred feet, has intersected elongate and interconnected

fractures connected to fractures encountered by gas wells. The now constant flow of natural gas to Bill Ely's well, which may be ignited continuously 24 hours per day (Bill Ely, pers. comm.), documents that the pre-gas well situation has been altered by gas drilling. This new natural gas flow path to Bill Ely's well establishes that Cabot has uncontrolled gas excursions toward this well and others (e.g., Scott Ely well). This new presence of natural gas, where it never was before gas well construction, documents that hydraulic pathways DO exist between gas wells and homeowner wells. If these flowpaths did not exist, then Bill Ely's well would remain as it did prior to gas well construction. It does not. Thus, natural gas excursions to locations that formerly did not have high levels of natural gas document both fracture interconnectivity at depth AND the presence of hydraulic pathways that are capable of transporting contaminants. If not immediately, it is likely that contaminants will move at slower groundwater flow rates than natural gas, potentially resulting in long-term aquifer contamination for hundreds of years, or more. To stop delivering clean water to homes already shown to be hydraulically connected to gas wells based on gas excursions (and verified by PA DEP consent order statements) would not be prudent because hydrogeologically gas flow through water is likely to occur faster than contaminant movement in groundwater.

14. Furthermore, Cabot's whole house treatment systems are inadequate to permanently replace or restore the Petitioners' water supplies. Water testing conducted by Cabot revealed the presence of ethylene glycol in water after treatment by the whole house treatment system. Additionally, the treatment system selected solely by Cabot cannot be installed in properties whose well water has high iron content. This has prevented the installation in at least one property whose owner has elected to received such system (not a Petitioner), and precluding the installation at many, if not most, of the Petitioners' properties. Annexed as **Exhibit 7** is an email from Suzanne Johnson.

15. Based on my review of the available sampling data, my knowledge of the many varieties of chemicals used in the hydraulic fracturing process, my observations of the Petitioners' water, and my assessment of the hydrogeologic conditions present, I can conclude with scientific certainty that the Petitioners' untreated well water supplies are not safe for human consumption. If the Petitioners were subjected to drinking untreated water from their supply wells, their immediate health and safety would be put in jeopardy. State sign-off on supposedly clean, potable, groundwater should not occur while people's health remains in serious jeopardy from numerous unknown and untested chemicals. Because the multitude of fracking related chemicals are not known and have not been tested for in the Petitioners wells, it is unreasonable and without foundation to believe that standard water treatment systems must be and are capable of removing fracking-related contaminants. In the absence of gas company-specific tracers, the list of well-specific chemical analytes MUST be significantly increased to include numerous NON-NATURALLY OCCURRING toxic contaminants that do not have MCLs (e.g., 2-butoxyethanol, formaldehyde). The presence of any of these parameters in freshwater resources (e.g., homeowner wells, springs, streams, lakes) should provide sufficient documentation of uncontrolled gas field excursions while providing justification for the installation of water distribution pipes from a safe, potable, water source.

16. As such, the PADEP should direct Cabot to continue supplying fresh bulk and bottled water to the Petitioners until it is able to permanently replace or restore their affected water supplies to standards that are safe for human consumption and in compliance with the Pennsylvania Drinking Water Standards. In the high and almost certain likelihood that this cannot be achieved, Cabot should be required to extend a public water supply line to all adversely impacted homes. Until such time as much more comprehensive groundwater testing is conducted for the hundreds of known toxins used in hydraulic fracturing fluids, no homeowner should be removed from water deliveries.

Paul A. Rubin

Paul A. Rubin

Sworn to before me this
23rd day of November, 2011

Rubin
Exb D

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RE: Technical Justification in Support of Requiring Cabot to Immediately Resume Water Deliveries to Adversely Impacted Residents of Dimock, PA [Public statement made at a press event in held in Dimock, PA on Dec. 6, 2011]

My name is Paul Rubin. I am a hydrogeologist and President of HydroQuest – an environmental consulting firm. I am here to discuss my professional hydrologic concerns relating to the water supply of residents of the Carter Road area.

First, let's dispel the question as to whether or not groundwater between gas wells and homeowner wells has become and remains contaminated. It has and will continue to be. Worse yet, it is likely that the contaminant level will rise slowly to a peak and then subside slowly over decades or centuries. Groundwater flow rates in bedrock aquifers can be either very rapid or very slow, depending on available pathways. But, before we discuss this, let's take a look at some recent Dimock area water quality data.

Existing Contaminant Thresholds & Premature Determination of Clean Groundwater

Unfortunately, the State's determination as to whether groundwater is contaminated or not has been by comparison with a pretty small and select number of chemicals that have PA Maximum Contaminant Level (MCL) standards. Recently, Cabot provided a set of water analyses for review. Apparently, this data forms the basis of the State's determination that Dimock groundwater is now safe to drink. It also must form the basis of the preliminary conclusion reached by EPA that echoes the State determination. Let's hope that EPA retracts this preliminary assessment after they have had more time to review the chemical data. As the data stands now, there are five major problems with reaching the conclusion that Dimock groundwater is not contaminated. These are: 1) there is no location map or key to inform the reader as to where all the assorted sample sites are, 2) many area wells known to be adversely affected were not sampled, 3) visually obvious MCL violations were ignored, 4) the conclusions reached have failed to factor in the hydrogeologic setting and groundwater flow, and 5) Cabot's **own data reveals existing contamination in excess of State MCL drinking water quality standards.**

Recent Example Violations of Maximum Contaminant Level (MCL) Drinking Water Quality Standard Thresholds

Looking first at the **Sautner well,** Cabot's recent data **shows the iron level to be 5000 ug/l, some 16.7 times the MCL of 300 ug/l. Three other sample locations** in Cabot's recent data set also **reveal iron concentrations ranging from 3.7 to 5.3 times the MCL standard** (e.g., Roos well). **Five sample locations, including Sautner, were found to have manganese concentrations of up to 4 times the PA MCL drinking water standard for manganese of 50 ug/l.**

Importantly, Cabot had two sets of water samples analyzed for certain chemical parameters, including metals – complete with two sets of data findings. One set was analyzed for total metals. This is exactly how the water flows from the tap – just as the Sautner's drank it in the past. The second sample set was filtered through a very small, 0.45 micron, filter membrane to remove some of the metals. This did reduce metal concentrations below the MCL standard in some of the wells, but three still failed to meet State SMCL standards for manganese. PA state code does not call for unnatural filtration of water before reporting the results. This is not realistic and certainly does not reflect the natural, unfiltered, groundwater residents enjoyed for years before gas drilling operations began. Not surprisingly, it appears that this special analytical approach formed much of the basis of the State's determination to have Dimock residents now drink well water that is contaminated and violates PA State Safe Drinking Water Regulation standards. This is not reasonable and should be retracted.

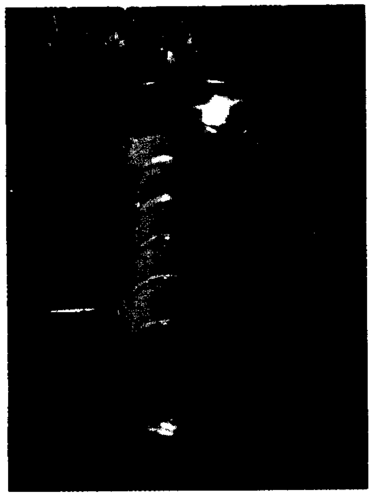
There are other contaminants also documented in recent sampling efforts. For example, Cabot's recent sampling of unfiltered **Sautner well water detected 10 ug/l of lead, twice the MCL of 5 ug/l.**

It is worth taking a look at some nearby residential wells that were apparently not sampled by Cabot in their recent sample round and thus apparently not factored into the determination to stop Dimock water deliveries. Recent sampling was conducted on Nov. 22 for the firm of NapoliBernRipkaShkolnik & Associates. **The Carter well was found to have lead and manganese at levels of 5 and 2.6 times State MCL levels and iron at 5.7 times the PA State MCL standard.** These are all obvious violations of PA Safe Drinking Water Regulation standards.

Let's take a look at water from the **Scott Ely well** that Cabot and the State of PA have determined is now suitable for ingestion. Prior to gas drilling activities, Scott Ely's groundwater was clear, potable, and did not require filtration. This is it here now in this one gallon jug (hold up water sample). As I tell you only some of what is in it, consider whether you would allow yourself and your family to drink and bathe in it. Within the last two weeks, this water sample **was found to have lead and manganese at 5.8 and 10 times State MCL levels and arsenic at 15 times the State MCL level**. Data received within the last few hours **revealed an aluminum concentration of 28 mg/l, some 140 times the State MCL**. This is cause for great concern. Aluminum is a potent neurotoxin that may be linked to dementia, including Alzheimer's like health symptoms. Similarly, **iron was detected at 34 mg/l, some 113 times the State MCL Safe Drinking Water standard**. While all analyses have not been completed, preliminary findings also indicate the presence of low level hexanes, octanes, and decanes. However, the high pH of the water indicates the presence of SIGNIFICANT other frack-related chemicals that are both unknown and untested –chemical compounds that do not have MCLs – chemicals that potentially present long-term chronic exposure to toxins and carcinogens.

The **pH** of the water has repeatedly been **found to be** around 9.5 – a very basic water, some **10 times the normal outer MCL State drinking water standard range** of pH 8.5 and, quite likely, 100 times that of a more normal Dimock groundwater pH. This is highly unusual and extremely troubling. Something is VERY wrong with this water. Here, you can see it as it now comes out of the well – the **color** of chocolate milk, **five times the maximum allowable PA MCL Safe Drinking Water standard** (75 vs. 15 color units) **for color**. Even after weeks, it still does not settle out.

Clearly, when we begin to examine only some of the water quality data available, even excluding a host of other chemicals I won't address at this time, we are left wondering how it is possible that a determination to start drinking this water could possibly have been made. This decision must be reversed immediately. From both health and liability standpoints, this is not acceptable.



Scott Ely Well Water

Hydrogeologic Characterization

Now, let's take a look at the larger hydrogeologic picture here in Dimock. This starts with an understanding of whether contaminants can physically move from gas wells to homeowner wells? The answer is yes, they already have and will continue to do so. The key here is to understand that for this to occur there must be open, hydraulically efficient, pathways that both groundwater and contaminants can follow. To a great extent, these pathways here are along fractures and faults. Here are two figures that show major fracture directions and fault offset bedrock layers as found in a bedrock quarry along Carter Road. (Show and discuss them.)

Fractures and faults are important contaminant transport pathways

It is along these pathways that natural gas, metals, surfactants, and other contaminants have already moved from upland areas down gradient to homeowner wells. This demonstrates that pathways are open now and moving gas field contaminants. These pathways will continue to function far into the future. They will not magically seal up and contaminant migration will cease. This is not how hydrologic flow systems operate. Only the regulators view the issue of well contamination in gas fields as ending on a few year basis. This is unrealistic.

Hydrogeologically, we need to consider slow groundwater flow rates. Some contaminants may arrive rapidly via fractures, while others may arrive over decades or centuries. Contaminants we see in the early years following drilling may only reflect the first arrivals. Thereafter, contaminant levels will rise slowly to a peak and then subside slowly. In time, these contaminants will reach down valley locations where larger population centers commonly use groundwater for supply purposes. While chemical concentrations may not always exceed MCLs, long-term chronic exposure to numerous unknown and untested chemicals presents a great health risk. Again, no standards exist and no testing has been conducted for many of the toxic and carcinogenic chemicals injected underground during the hydrofracking process. In the absence of gas company specific fluid tracers that should be mandated in all drilling fluids and in the face of numerous unknown chemicals, homeowners with contaminated wells here in Dimock are left in a most unfortunate and compromised position.

Chronic, Low-Level, Chemical Exposure & Water Treatment Limitations

Chronic exposure to low-level fracking chemicals is too great a medical risk to expect. Furthermore, I would not consider it wise for any water treatment company to state that their systems are capable of removing the many hundreds of untested and undocumented chemicals that may be present. The liability associated with providing a water treatment system that may not be capable of removing numerous undocumented and untested contaminants would not be something I would consider assuming if I were a company's CEO. The risk to homeowners and water treatment companies simply is not warranted. Homeowners should not put their trust in claims made by water treatment companies to purify such water.

Until such time as gas companies voluntarily use tracers or are forced to use company specific tracers that can readily be tested in homeowner wells, it is not wise for homeowners to potentially expose themselves to untested chemicals, even if a few that have been tested for appear to temporarily pass MCL standards. The likelihood of restoring contaminated gas field aquifers is essentially zero, especially since a sizable contaminant source area will remain within gas wells, readily available for transport to freshwater aquifers WHEN well sealant materials fail (see http://hydroquest.com/Hydrofracking/ [Aquifer Protection Expert Fact Sheet Front]). Water deliveries should be continued until such time as a water line is installed from a safe, potable, source.

Community Spirit and a Call For Civility

Lastly, it has come to my attention that some neighbors and residents of the Dimock area have not been supportive of adversely affected Carter Road area residents. I have shared only some of the many existing groundwater contaminant problems with you. These are only too real, as are the potential risks associated with ingesting and bathing in this water. I would never expose my sons or my daughter to Carter Road/gas field water for either drinking water or bathing purposes.

As you look at Scott Ely's water here and have heard of only some of the contaminants actually present in this water, consider if you would drink it and expose your family to it. Given the hydrogeologic situation and some water quality data, it is important to note that the State of PA has mistakenly declared adversely affected well water as safe to drink. It is time to consider that perhaps until now you have not truly understood the present and long-term contaminant situation. It is the holiday season. It is a time to mend fences and support your community, as you yourselves would wish if you were in their shoes. Thank you.

Conclusions

Water in many Carter Road area wells is <u>not</u> safe to drink. Chemical results, including Cabot's own recent sample data, document contamination of aquifer water. Some of this data, and new data, have been presented today. Natural gas and chemical excursions document open hydraulic pathways between gas and homeowner wells. Clearly, it was premature to stop water deliveries to adversely impacted Dimock residents, thereby leaving them exposed to contaminant levels in excess of PA Safe Drinking Water standards, as well as numerous other fracking chemicals that may be present but have not been tested for. This is also true of other adversely impacted residents who have not, but should also receive safe water deliveries. Immediate and chronic low-level exposure to gas industry chemicals constitutes an emergency situation.

Because groundwater flow rates are slow, chemical exposure is likely to continue for decades, centuries, or far longer. Since the gas industry does not use tracers that could readily be added to fracking and drilling fluids, residents have no means of determining which of hundreds of toxins they may be exposed to on a daily basis, much less whether common water treatment systems are effective in treating proprietary and untested chemicals. For these reasons, these people's well water is not safe to drink. Thus, I strongly recommend that Cabot's water deliveries be resumed immediately and continued until an alternate, safe, drinking water supply is piped to their homes.

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"*The dangers to our waters are, in fact, extreme. The damage may not show up for years, the ruination of our* water may at first be invisible and in the end irreparable." Cyla Allison, Ph.D., Eight Rivers Council, West Virginia

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DELAWARE RIVERKEEPER® NETWORK

Mid-Atlantic States Section of the Air and Waste Management Association

Wastewater Produced by Natural Shale Gas Production
Some Regulatory and Management Issues

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Environmental Aspects of Shale Gas Development Conference
March 27, 2012

Wastewater and other waste products produced during oil and gas drilling and production has the potential to negatively impact groundwater and surface water.[1] This paper will focus on unconventional sources of natural gas, defined as sources that use more complex and expensive technologies such as hydraulic fracturing and horizontal drilling,[2] specifically shale gas.

What are the Numbers?

The U.S. Department of Energy's Energy Information Agency (EIA) sets current U.S. consumption at about 23.5 Trillion cubic feet (Tcf) per year. According to a report by the General Accountability Office (GAO), the production of natural gas in the U.S. produces an estimated 56 million barrels of produced water per day, but this is likely underestimated due to incomplete and out of date data (primarily 2007)[3]. For instance, shale gas production has increased significantly since 2007; the GAO reports an average annual growth rate of 48% from 2006 to 2010. Shale gas, according to the EIA, accounts for about 23% of the nation's total gas production.

The amount of wastewater being produced today has sharply increased in the past five years due to the advent of shale gas development. In Pennsylvania, for instance, between 2005 and 2008, there were 251 shale gas well drilling permits issued; from January 1, 2008 to March 21, 2012 10,122 shale gas well permits were issued. From 2005 through to 2008 150 Marcellus Shale gas wells were drilled; from January 1, 2008 to March 21, 2012 there were 5,127 Marcellus Shale wells drilled. The U.S. Environmental Protection Agency (EPA) remarked on the "remarkable speed" of the growth of the natural gas industry in Pennsylvania in a letter dated March 7, 2011.[4]

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[1] US General Accountability Office, ***Information on the Quantity, Quality, and Management of Water produced during Oil and Gas Production***, GAO-12-56, January 2012.
[2] Ibid.
[3] Ibid.
[4] USEPA letter from Shawn M. Garvin, Regional Administrator to The Honorable Michael Krancer, Acting Secretary, PADEP, 3.7.11.

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Pennsylvania has joined the nine other states that yield 90% of the volume of produced water in the United States[5].

According to the Department of Energy, 100,000 new shale gas wells can be expected nationally.[6] According to state predictions, 50,000 new natural gas wells could be drilled in Pennsylvania[7] and 40,000 in New York. Estimates in the Delaware River watershed alone range up to 32,124 (from the Delaware River Basin Commission) to 64,000 gas wells (National Park Service). Whatever the ultimate number, the expected increase in shale gas development will mean an increase in wastewater volume.

"Produced water" -- water produced from wells during gas and oil exploration and production -- is made up of water that exists in the geologic formations that are disturbed by drilling and extraction processes ("formation water") and can also contain fluids injected to stimulate production. In shale gas processes, the mix of water, chemicals, and proppants that are injected during hydraulic fracturing returns to the surface mixed with formation water as "flowback".

According to PADEP, 31,093,611.51 barrels, or 1,339,951,662 gallons of wastewater was produced by shale gas wells in 2011, according to operator reports.[8] The amount of flowback that initially erupts to the surface in Pennsylvania shale gas wells varies but is estimated to be about 10% of the volume injected; on average, approximately 5 million gallons of water is used to hydraulically fracture the well. Considering the large number of wells involved (PADEP issued 5,728 drilling permits for oil and gas wells in 2011; 2,907 new oil and gas wells were spudded in 2011)[9], significant management challenges are posed by the volume of produced water.

<u>What are the Management Issues?</u>

According to the GAO, produced water is "generally of poor quality, with levels of contaminants varying widely".[10] Treatment is required before the wastewater can be reused or discharged. Hydraulic fracturing methods, using chemicals and proppants under high pressure in deep geologic formations with high levels of naturally occurring contaminants can yield poorer quality produced water than other extraction processes.[11] A previous study from the U.S. Department of Energy concludes that produced water from gas drilling is 10 times more toxic than those from off shore oil drilling.[12]

Contaminants "...can include, but are not limited to: salts (chlorides, bromides, and sulfides of calcium, magnesium, and sodium); metals (including barium, manganese, iron, and strontium); oil, grease, and dissolved organics (including benzene and toluene); naturally occurring radioactive materials; and production chemicals from hydraulic fracturing...Exposure to these contaminants at high levels may pose risks to human health and the environment".[13]

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[5] Ibid.

[6] U.S. Department of Energy Secretary of Energy Advisory Board, ***Shale Gas Production Subcommittee Second Ninety Day Report***, 11.18.2011.

[7] PA Bulletin, Doc_ No_ 10-1572.mht

[8] https://www.paoilandgasreporting.state.pa.us/publicreports/Modules/DataExports/DataExports.aspx

[9] PADEP website, 1.24.12

[10] US General Accountability Office, ***Information on the Quantity, Quality, and Management of Water Produced During Oil and Gas Production***, GAO-12-56, January 2012.

[11] Ibid.

[12] U.S. Dept. of Energy, Argonne National Laboratory, "A White Paper Describing Produced Water from Production of Crude Oil, Natural Gas, and Coal Bed Methane", January 2004.

[13] Ibid.

The Marcellus Shale contains radionuclides including uranium-238, thorium-232, and their decay products. Radioactive concentrations in the Marcellus Shale formation are at concentrations 20 to 25 times background, making shale gas wastewater extremely radioactive.[14] The produced water from Marcellus Shale has higher levels of radionuclides than water from Barnett Shale wells, according to the GAO.[15]

Sampling and data-gathering by New York State detected radiological parameters in Marcellus Shale flowback, including Radium-226[16], the longest lived isotope of radium with a half-life of 1600 years. Gross Alpha, Gross Beta, Total Alpha Radium and Radium-228 were also found.[17] This is a significant wastewater management issue because radioactivity poses human health risks.

Radium-226, a decay product of the Uranium-238 decay chain, is taken up like calcium into bone[18] where it concentrates. Radium-226 can cause lymphoma, bone cancer, and diseases that affect the formation of blood, such as leukemia and plastic anemia. The radioactive decay product of radium is radon, which is very dangerous and is the second leading cause of lung cancer in the United States.[19] EPA has set federal air limits, cleanup standards, and a maximum contaminant level for radium 226 and 228 under the Safe Drinking Water Act due to human health hazards.[20] EPA has the authority to regulate all Naturally Occurring Radioactive Materials (NORM), but generally has not done so, leaving a regulatory gap in terms of human health and a lack of data regarding impacts to the natural environment, such as aquatic life.[21] These regulatory and data gaps pose additional management challenges.

In a letter to PADEP in 2011, EPA highlighted the presence of radionuclides, along with other contaminants, as present in wastewater resulting from gas drilling operations and emphasized the importance of investigating the presence of radionuclides in public water supplies and their persistence in wastewater effluent.[22] EPA pointed out that this information is essential to the development of controls to protect public health and aquatic life in receiving water bodies.[23] As a result, testing for radionuclides in Pennsylvania has been required by EPA for water supply facilities and wastewater plants; other measures have been suggested to PADEP and/or have been taken directly by EPA over the past year, including independent EPA inspections, monitoring, data reviews, and compliance determinations. How these actions will shape the management and ultimate fate of gas drilling wastewater remains to be seen.

Other dangerous contaminants in wastewater pose risks to human health and the environment. New York tested flowback from Marcellus Shale gas extraction operations in Pennsylvania and

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[14] Marvin Resnikoff, Ph.D., Radioactive Waste Management Associates, "Comments on Marcellus Shale Development", October 2011.
[15] US General Accountability Office, ***Information on the Quantity, Quality, and Management of Water Produced During Oil and Gas Production***, GAO-12-56, January 2012.

[16] Ibid. Table 5.24.
[17] Ibid.
[18] http://www.epa.gov/radiation/radionuclides/radium.html#inbody
[19] Ibid.
[20] Ibid.
[21] Glenn C. Miller, Ph. D., ***Comments to Delaware Riverkeeper Network on the Delaware River Basin Commission's Draft Proposed Natural Gas Development Regulations***, 2011.
[22] USEPA letter from Shawn M. Garvin, Regional Administrator to The Honorable Michael Krancer, Acting Secretary, PADEP, 3.7.11.
[23] Ibid.

West Virginia and found 154 parameters.[24] Many are chemical hazards, many are known to effect human health and the environment.

The GAO highlights some of the health impacts of these chemicals.[25] For instance:

> EPA advises that high levels of barium increase blood pressure.[26]
>
> PADEP acknowledges that bromide is a key parameter of concern in the effluent because it can form brominated disinfection by-products (DBP's) in water supplies. These are a drinking water hazard because of the propensity for the brominated DBP's to form trihalomethanes, which can cause cancer.[27]
>
> The International Agency for Research on Cancer and the EPA have determined that benzene is carcinogenic to humans; benzene is naturally occurring in the Marcellus shale and is also a hydraulic fracturing additive. The EPA has set the maximum contaminant level of benzene in drinking water at 5 parts benzene per billion parts of water (5 ppb).[28] A very small amount of benzene can contaminate water beyond safe drinking water standards.

The depth of the shale formation influences the salt and mineral content of the produced water; generally, the deeper the formation, the higher the salt and minerals. Produced water from Marcellus Shale can have salt and mineral levels 20 times higher than coalbed methane wells, for instance.[29] High salt levels (represented as Total Dissolved Solids or TDS), typical of Marcellus Shale gas wastewater, are toxic to the natural environment and can carry significant adverse impacts, including impairment and death of aquatic life. In 2010, DEP stated that "…many of the rivers and streams of Pennsylvania have a very limited ability to assimilate additional TDS, sulfates and chlorides because of elevated levels from historic practices".[30]

As an example, stream contamination due to extremely high TDS and chloride levels led to a cascade of ecosystem changes in Dunkard Creek in 2009, where one of the worst ecological disasters in modern times occurred on this popular fishing stream that winds back and forth across the Pennsylvania and West Virginia border. Over a period of one month, 22,000 fish died and at least 14 species of freshwater mussels were destroyed along with all other aquatic life for 35 miles of stream.[31] Basically, the stream turned from fresh water to salt water, killing everything with gills.

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[24] New York State Department of Environmental Conservation, ***Revised Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas, and Solution Mining Regulatory Program, Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and other Low-Permeability Gas Reservoirs***, September 2011, Table 5.9.
[25] US General Accountability Office, ***Information on the Quantity, Quality, and Management of Water Produced During Oil and Gas Production***, GAO-12-56, January 2012.
[26] Ibid.
[27] PADEP "Permitting Strategy for High Total Dissolved Solids (TDS) Wastewater Discharges", April 11, 2009.
[28] http://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=38&tid=14
[29] US General Accountability Office, ***Information on the Quantity, Quality, and Management of Water Produced During Oil and Gas Production***, GAO-12-56, January 2012.
[30] PADEP "Permitting Strategy for High Total Dissolved Solids (TDS) Wastewater Discharges", April 11, 2009.
[31] Adam Federman, "What Killed Dunkard Creek?, Earth Island Journal, Winter 2012. http://www.earthisland.org/journal/index.php/eij/article/what_killed_dunkard_creek

In its Permitting Strategy, DEP goes on to discuss the overload of TDS in the Monongahela River: TDS and sulfates reached historic highs in 2008 (this condition recurred in 2009), exceeding water quality standards at the water facilities that supply water to over 325,000 people in the basin, including Pittsburgh. DEP also lists South Fork Tenmile Creek, the Beaver and Conemaugh Rivers and the West Branch of the Susquehanna River as being overloaded with high TDS concentrations.[32]

PADEP adopted an effluent standard of 500 mg/L as a monthly average for TDS in 2010 but this is based on limited data and not protective of aquatic life, according to recent studies,[33] but is consistent with EPA recommended standards. Pennsylvania also adopted an effluent standard of 250 mg/L of total chlorides as a monthly average and 250 mg/L of total sulfates as a monthly average.

The Philadelphia Water Department commented in support of the chloride standard due to the need to control salinity in the drinking water they provide. The Water Department expressed concern that the elevated salt content of shale wastewater (up to 40,000 mg/L of chloride) and the difficulty in balancing the already high chloride concentration in the City's raw water supply due to proximity to the estuary. High chloride content erodes facility piping and infrastructure and negatively impacts human health for sensitive individuals.[34]

Concern was expressed by the City of Philadelphia about whether these contaminants and others in gas drilling wastewater will make it more difficult for the City as a water supplier to meet Safe Drinking Water Act standards.[35] This concern is magnified statewide considering that there are 349 drinking water suppliers in Pennsylvania that rely on surface water or groundwater directly influenced by surface water.[36]

Arsenic, mercury, and hydrocarbons, as well as many other toxic contaminants in shale gas wastewater are also of concern. For example, in natural gas production in Texas, the arsenic content in wastewater has both a high hazard quotient and a risk factor greater than 10,000, which requires a cleanup of a site; these measurements were not done by New York for the revised draft SGEIS and it is unknown if this is being tracked in Pennsylvania. According to EPA, non-cancer effects of arsenic can include thickening and discoloration of the skin, stomach pain, nausea, vomiting; diarrhea; numbness in hands and feet; partial paralysis; and blindness. Arsenic has been linked to cancer of the bladder, lungs, skin, kidney, nasal passages, liver, and prostate. EPA has set the arsenic standard for drinking water at .010 parts per million (10 parts per billion).[37]

Mercury, likewise, is a poison found in gas drilling wastewater[38] that has severe health impacts.[39] EPA has set a safe drinking water limit of 2 ppb, reflecting that tiny amounts can contaminate water supplies and will have direct health effects.

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[32] PADEP, "Permitting Strategy for High Total Dissolved Solids (TDS) Wastewater Discharges", April 11, 2009.
[33] Delaware Riverkeeper Network, Comment to PA Environmental Quality Board re. 25 PA Code Ch. 95 Wastewater Treatment Requirements, dated 2.12.2010.
[34] City of Philadelphia Water Department Comments on the Environmental Quality's Board's Proposed Regulation # 7-446 (#2806) to amend 25 Pa. Code Chapter 95, 2.11.2010.
[35] Ibid.
[36] PA Bulletin, DOC No. 10-1572, 25 PA. CODE CH. 95, 8.21.10.
[37] http://water.epa.gov/lawsregs/rulesregs/sdwa/arsenic/index.cfm
[38] New York State Department of Environmental Conservation, ***Revised Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas, and Solution Mining Regulatory Program, Well Permit***

New York sampling also has found unique contaminants such as acrylonitrile[40], presumably from use as a component of acrylonitrile-butadiene-styrene in-situ polymerization to increase the utility of a propping agent.[41] It is a human health hazard and is "reasonably anticipated" to cause cancer.[42] The composition of shale gas wastewater offers complex and challenging management issues.

Endocrine disrupting chemicals (EDC) used in hydraulic fracturing fluids and found in flowback are of special concern due to the biological effects of these constituents at extremely low concentrations. Scientists and health professionals are beginning to analyze these materials and measure their impacts on human health in a different way, testing these compounds at very low levels in the range of human exposures and at various endpoints.[43] In an effort to protect human health from these very dangerous materials, scientists are concluding that there are no safe doses for endocrine disrupters; the fact that they have biological effects proves that EDC's have biological activity – what the induced effects are is the question.[44]

Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and other Low-Permeability Gas Reservoirs, September 2011, Table 5.9.

39 **Mercury CAS #: 7439-97-6, How can mercury affect my health?** The nervous system is very sensitive to all forms of mercury. Methylmercury and metallic mercury vapors are more harmful than other forms, because more mercury in these forms reaches the brain. Exposure to high levels of metallic, inorganic, or organic mercury can permanently damage the brain, kidneys, and developing fetus. Effects on brain functioning may result in irritability, shyness, tremors, changes in vision or hearing, and memory problems. Short-term exposure to high levels of metallic mercury vapors may cause effects including lung damage, nausea, vomiting, diarrhea, increases in blood pressure or heart rate, skin rashes, and eye irritation. **How likely is mercury to cause cancer?** There are inadequate human cancer data available for all forms of mercury. Mercuric chloride has caused increases in several types of tumors in rats and mice, and methylmercury has caused kidney tumors in male mice. The EPA has determined that mercuric chloride and methylmercury are possible human carcinogens. **How does mercury affect children?** Very young children are more sensitive to mercury than adults. Mercury in the mother's body passes to the fetus and may accumulate there. It can also pass to a nursing infant through breast milk. However, the benefits of breast feeding may be greater than the possible adverse effects of mercury in breast milk. Mercury's harmful effects that may be passed from the mother to the fetus include brain damage, mental retardation, incoordination, blindness, seizures, and inability to speak. Children poisoned by mercury may develop problems of their nervous and digestive systems, and kidney damage. http://www.atsdr.cdc.gov/tfacts46.pdf

40 New York State Department of Environmental Conservation, ***Revised Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas, and Solution Mining Regulatory Program, Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and other Low-Permeability Gas Reservoirs***, September 2011, Table 5.9.

41 **Acrylonitrile CAS ID #: 107-13-1**, **Affected Organ Systems:** Developmental (effects during periods when organs are developing) , Hematological (Blood Forming), Neurological (Nervous System), Reproductive (Producing Children; **Cancer Effects:** Reasonably Anticipated to be Human Carcinogens; **Chemical Classification:** None; **Summary:** Acrylonitrile is a colorless, liquid, man-made chemical with a sharp, onion- or garlic-like odor. It can be dissolved in water and evaporates quickly. Acrylonitrile is used to make other chemicals such as plastics, synthetic rubber, and acrylic fibers. A mixture of acrylonitrile and carbon tetrachloride was used as a pesticide in the past; however, all pesticide uses have stopped. http://www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=78

42 Ibid.
43 Vandenberg et. al., "Hormones and Endocrine-Disrupting Chemicals: Low-Dose Effects and Nonmonotonic Dose Responses", The Endocrine Society, doi:10.1210/er.2011-1050, 3.14.12.
44 Laura Vandenberg, Tufts University, "There Are No Safe Doses for Endocrine Disruptors", Environmental Health News, 3.12

Suspected EDC's found in gas drilling wastewater include arsenic and selenium; hydraulic fracturing fluids may contain others such as 2BE, 2-Ethylhexanol, and Crystalline Silica. None of these chemicals are targeted for removal from gas drilling wastewater. The use and/or presence of these chemicals highlights the problem that many of the dangerous constituents of gas drilling wastewater are either unknown or lack testing for human health and natural environment impacts.

Due to inadequate regulation and lack of sophisticated study designs that can accurately identify the effects of these contaminants, entire classes of chemicals are not regulated in the environment and so are not captured in the treatment and management effort. As stated by Linda Birnbaum, Director, National Institutes of Health, "It is time to start the conversation between environmental health scientists, toxicologists, and risk assessors to determine how our understanding of low-dose responses influence the way risk assessments are performed for chemicals with endocrine-disrupting activities. Together, we can take appropriate actions to protect human and wildlife populations from these harmful chemicals and facilitate better regulatory decision making".[45]

The GAO points out that a number of options are used to manage produced water, that "most produced water is minimally treated" and that cost is the "primary driver" in decisions about how to manage and treat the wastewater.[46]

How Is Gas Drilling Wastewater Handled Today?

Underground Injection

Most gas and oil wastewater produced in the United States (U.S.) is injected into underground disposal wells. There are 150,855 injection wells that are permitted to inject produced water in the U.S., although not all are in use. About 20% of these are used for disposal, the rest are used for "enhanced recovery", a means of stimulating resource extraction. In Pennsylvania, there are 1,861 injection wells, most all of them used for enhanced recovery; there are only six currently active injection wells for produced water disposal.[47] EPA, who regulates the Underground Injection Control program in Pennsylvania, says there is increased interest from operators for new injection wells in the state.[48] Currently, wastewater that is disposed in injection wells is trucked from Pennsylvania to Ohio and West Virginia.

Surface water discharge

Surface water discharge of produced water accounted for less than 1 percent in 2007 in the U.S. The amounts increased with Marcellus Shale development in Pennsylvania, where surface discharges became "common".[49] However, PADEP officials told EPA that this fell off after the state implemented its stricter Chapter 95 effluent limitations, as discussed above, although surface discharge is not prohibited in the State.[50]

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[45] Linda S. Birnbaum, Director, NIEHS and NTP, National Institutes of Health, U.S. Department of Health and Human Services, "Environmental Chemicals: Evaluating Low-Dose Effects", doi:10.2189/ehp.1205179, Environmental Health Perspectives, Vol. 120, Number 4, April 2012.
[46] US General Accountability Office, ***Information on the Quantity, Quality, and Management of Water Produced During Oil and Gas Production***, GAO-12-56, January 2012.
[46] PADEP "Permitting Strategy for High Total Dissolved Solids (TDS) Wastewater Discharges", April 11, 2009.
[47] US General Accountability Office, ***Information on the Quantity, Quality, and Management of Water Produced During Oil and Gas Production***, GAO-12-56, January 2012.
[48] Ibid.
[49] Ibid.
[50] Ibid.

EPA, in its March 2011 letter, strongly advised PADEP that existing discharge permits for Publicly Owned Treatment Works and centralized waste treatment facilities did not allow the acceptance of gas drilling wastewater without "critical provisions necessary to effective processing and treatment" of the wastewater.[51] EPA has inserted itself into PADEP's review of these facilities for better accountability. Doubtless this interest from EPA has had an effect on surface water discharges there. One new treatment facility has gone into operation under the new effluent standards[52]; several "brine" facilities that were "grandfathered" under the old regulations continue to discharge to surface water, as do some sewage treatment facilities employing pre-treatment.

The issue of how to dispose of sludge and residue from treatment facilities that remove TDS and other contaminants is yet another management challenge. For example, removal of salts from this wastewater will probably require use of membrane systems to recover the majority of the water. However, this will leave large amounts of salty brines for disposal and will require further treatment for safe management/disposal.[53] Other contaminants removed that will be concentrated into residual sludge can also reach highly toxic levels and require special handling. The development of facilities and landfills designed to safely manage this waste is needed. The acceptable treatment and disposal options, including how the residual concentrate will be managed, should be addressed comprehensively on a national level.

Currently, no set of regulations for waste produced during hydraulic fracturing exist. EPA is developing standards for shale gas and coalbed methane wastewater; the rules are expected to be proposed in 2014. This will only address part of the management issues and will leave some critical loopholes in place that pose environmental threats. Because of a 1988 oil and gas industry waste exemption from the Resource Conservation and Recovery Act (RCRA), these regulations will not regulate the wastewater as hazardous, even though there are hazardous constituents in the wastewater.[54] The list of RCRA exempt wastes includes produced water, drilling fluids and muds, drill cuttings, hydrocarbons, hydraulic fracturing fluids, pit sludges, certain gases and hydrocarbons, workover wastes and sediment from the bottom of tanks.[55] The treatment regulations will be proposed by EPA without reclassifying the waste, which will not address the essential problem that hazardous waste is being handled as if it were not hazardous, posing pollution issues. There is also no incentive for companies to minimize hazardous waste since they do not have to meet the high level of management and treatment this hazardous waste requires for all other generators.

<u>Reuse for hydraulic fracturing</u>

Some produced water is reused to hydraulically fracture additional wells. Reuse is attractive to an operator because it can reduce the amount of newly withdrawn water required, although the amount recovered as flowback is relatively small, about 10% of the injected volume in Pennsylvania. It can greatly reduce the costs of disposal, primarily because transportation of

[51] USEPA letter from Shawn M. Garvin, Regional Administrator to The Honorable Michael Krancer, Acting Secretary, PADEP, 3.7.11, p.2.

[52] Eureka Resources, Williamsport, PA, http://www.eureka-resources.com/

[53] Glenn C. Miller, Ph. D., ***Comments to Delaware Riverkeeper Network on the Delaware River Basin Commission's Draft Proposed Natural Gas Development Regulations***, 2011, p.3.

[54] Oil and Gas operations are exempt from portions of major federal environmental laws including: Clean Air Act; Clean Water Act; Safe Drinking Water Act; Resource Conservation and Recovery Act, Comprehensive Environmental Response, Compensation and Liability Act (the Superfund Law); and Emergency Planning and Community Right-to-Know Act. Amy Mall, et. al., Natural Resources Defense Council, ***Drilling Down***, October 2001, p.iv.

[55] U.S. Environmental Protection Agency, "Exemption of Oland Gas Exploration and Production Wastes from Federal Hazardous Waste Regulations," p. 10-11, http://epa.gov/osw/nonhaz/industrial/special/oil/oil-gas.pdf

wastewater to injection wells or treatment facilities adds substantial expense. Low cost on-site treatment technologies would need to be developed if reuse for hydraulic fracturing is to be widespread.[56]

Presently, there are no water quality standards set by government for produced water or flowback that is reused, posing a water quality problem. Operators reported to the GAO that they "treat the water to meet their own operating requirements" and that "...they had previously treated the water to a very high quality before reusing it for hydraulic fracturing, they are currently experimenting with lower levels of treatment."[57] For example, one operator reported that they used to remove the salt but no longer go to that expense to reduce operating costs and are considering eliminating other treatment if the reused wastewater can still meet their individual operating needs.[58]

One problem caused by reuse is the resulting concentration of certain contaminants. Reuse of this produced water will generally increase the contaminant load in the produced water in the subsequent well, both from additives and formation contaminants because there will be no dilution of the contaminants. If a leak occurs in the top few hundred feet in the well being fractured, the leak will contain very contaminated water under high pressure, and even a small leak can release large amounts of contaminants that can pollute aquifers and usable domestic water.[59]

Likewise, concentrated contaminants in flowback stored in open basins, as is allowed in most states, including Pennsylvania, provides the opportunity for highly toxic materials to leak, spill, or volatilize to the air. Also, when pits are closed after use is discontinued, it is legal under certain conditions in Pennsylvania to bury some pit waste on the well site. Also, the transport of these concentrated fluids for reuse between well pads in Pennsylvania is typically by plastic pipe over ground and even along and across streams, increasing the opportunity and likelihood for a release of pollutants to the environment. Leak detection of well bores, open pits, pipelines, and other critical junctures, including post-closure monitoring of well sites is not required in most states, including Pennsylvania. This presents a management problem in terms of avoiding pollution releases from natural gas wastewater and waste products.

The radioactive component is particularly challenging, since interstitial or formation water (the brine in the shale formation) can be highly radioactive (as concentrated as 15,000 pCi/L), so each time the water is reused, the radium is concentrated. This will result in TENORM, or technologically enhanced radium,[60] which is extremely toxic.

This problem magnifies as the radioactivity concentrates in wet rock cuttings that are produced by drilling, producing a waste with proportionally higher radioactivity. The cuttings, separated from the drilling fluid by screens, is more like a sand or dust and may contain up to 20% radioactive liquid.[61] These cuttings are typically disposed of in municipal landfills; some are buried on the well site. Testing for radioactivity should be required to properly manage this waste product and standards set for a maximum allowable level, based on natural background levels. The cuttings

[56] US General Accountability Office, ***Information on the Quantity, Quality, and Management of Water Produced During Oil and Gas Production***, GAO-12-56, January 2012.
[57] Ibid.
[58] Ibid.
[59] Glenn C. Miller, Ph. D., ***Comments to Delaware Riverkeeper Network on the Delaware River Basin Commission's Draft Proposed Natural Gas Development Regulations***, 2011.
[60] Marvin Resnikoff, Ph.D., Radioactive Waste Management Associates, "Comments on Marcellus Shale Development", October 2011.
[61] Ibid.

should be dewatered and the radioactive components removed. The radioactive waste should then be sent to a licensed disposal facility that is designed to handle radioactive wastes.[62]

Pollution Incidents are Multiplying

Current wastewater management practices are not adequate to protect the environment or the public. The dangerous constituents involved in the waste, the lack of adequate treatment technologies, the expensive and complex management issues presented, coupled with poor government oversight and lack of comprehensive regulation elevates this issue to one of national urgency.

EPA, the U.S. Department of Energy and other agencies are studying the issues involved.[63] The recent EPA investigation of groundwater contamination near Pavilion Wyoming[64] supports the finding of upward contaminant migration of non-naturally occurring gas field chemicals caused by natural gas extraction operations[65]; ongoing EPA analysis will attempt to pinpoint the mechanism involved but the report may help shed light on how drilling materials, hydraulic fracturing fluids, and formation water can migrate into fresh water aquifers. This issue is key to understanding how to manage and regulate these fluids.

The incidents of pollution are the subject of much public attention and continue to emerge.[66] Communities where drilling is occurring are experiencing water and air pollution, as well as other adverse impacts. Some of these are caused by poor performance by operators where violations of environmental permits by drillers have reached about 11 per day in Pennsylvania.[67] Some are caused by inadequate regulation and oversight of gas drilling, hydraulic fracturing, and well site and wastewater handling practices such as water, air and soil pollution being investigated in Washington County, Dimock, Beaver County, Butler County, Bradford County, Susquehanna County and other areas in Pennsylvania.[68] Some are due to deficiencies in the processes used to extract and produce shale gas, such as the overloading of Pennsylvania's streams with TDS[69] and the discharge of radioactive materials to waterways there.[70]

Conclusion

The management and regulation of wastewater produced during natural gas exploration and extraction is one of the most complex and challenging issues related to shale gas development. Regulation is a hodge-podge of state rules without an established federal regulatory floor.

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[62] Ibid.

[63] EPA is studying hydraulic fracturing impacts on drinking water; a final report is due in 2014, an interim report in 2012. http://www.epa.gov/hfstudy/ The Dept. of Energy is has issued several reports and research is ongoing. US General Accountability Office, ***Information on the Quantity, Quality, and Management of Water Produced During Oil and Gas Production***, GAO-12-56, January 2012, p.29-34.

[64] http://www.epa.gov/region8/superfund/wy/pavillion/EPA_ReportOnPavillion_Dec-8-2011.pdf

[65] Paul Rubin, HydroQuest, "Review of EPA Investigation of Groundwater Contamination near Pavillion Wyoming", March 9. 2012, p.1.

[66] http://www.nytimes.com/interactive/us/DRILLING_DOWN_SERIES.html

[67] http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?/Oil_Gas/OG_Compliance

[68] http://thetimes-tribune.com/news/dep-asks-gas-driller-to-help-remedy-franklin-twp-methane-spike-1.1287791#axzz1plWELhB8; http://www.propublica.org/article/so-is-dimocks-water-really-safe-to-drink ; http://shale.sites.post-gazette.com/index.php/news/daily-headlines/24402-3202012-another-nepa-methane-spike-new-well-sites-in-beaver; http://shale.sites.post-gazette.com/index.php/news/archives/24313-dep-fines-chesapeake-over-multiple-incidents; http://shale.sites.post-gazette.com/

[69] PADEP, "Permitting Strategy for High Total Dissolved Solids (TDS) Wastewater Discharges", April 11, 2009.

[70] http://www.nytimes.com/interactive/2011/02/27/us/natural-gas-documents-1-intro.html

Environmental impacts are not fully understood and yet mounting evidence of water contamination, air quality degradation, and community impacts is coming to light. The federal government is trying to play catch up in terms of policy, technical issues, and regulation while exemptions from major environmental laws remain in place and while shale gas development speeds ahead. A lack of ready-to-use comprehensive studies of the environmental and public health impacts allows critical issues regarding gas drilling wastewater management to go unaddressed while millions of gallons of wastewater are being produced every day, billions every year.

The industry is a major force in driving the direction of management today, well illustrated in regard to on-site treatment and reuse of wastewater for hydraulic fracturing where operators are making management decisions to meet their own economic needs. It is not reasonable to expect industrial interests to make decisions that provide protection to the public and the environment. The culture of gas and oil development is one that relies on exemptions from environmental laws, which allows a disconnect from corporate accountability and on large gaps in independent oversight, which provide favoritism to the industry at the expense of everything else. The conventional assumption is that without those props, the economic viability of these operations could falter.

Protection of public health and environmental resources is the job of government and is carried out in the regulatory structures we apply to activities such as resource extraction. Until a comprehensive approach to waste management is developed with federal standards that will prevent pollution and avoid degradation, shale gas drilling wastewater management issues will continue to pose unmet challenges.

Rubin

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Observations on Selected USEPA Summaries of Well Water Analysis from Dimock, Pennsylvania, 2012.

Ronald E. Bishop, Ph.D., CHO

I have reviewed biological and chemical analysis summaries of Dimock homeowners' wells identified by the USEPA as HW-02, HW-04, HW-06, HW-08a, HW-12 and HW-17. These are my observations:

The methods used to determine coliform and heterotrophic bacteria were very poorly performed: results from ten out of the twelve analyses reported were either rejected or clearly inconsistent. Therefore, they provide no basis to assess the presence or absence of microbes in the well water samples.

Minimum detection limits for glycol ethers and other detergents were unacceptably high. Further, no methylene blue active substance (MBAS) test results were reported, in spite of the fact that test results for nitrates (which might complicate MBAS interpretation with respect to surfactants) were reported. Therefore, no conclusions regarding pharmacologically significant concentrations of glycol ethers (particularly the endocrine disruptor 2-butoxyethanol) can be made from these results.

Methane concentrations were reported at over 7 parts per million (ppm or mg/L) in 4 of these wells: HW-02 (18 mg/L), HW-06 (23 mg/L), HW-08a (15 mg/L) and HW-12 (52 mg/L, a detonable concentration after outgassing at surface temperature and pressure). Ethane: methane ratios in these water samples ranging from 0.035 to 0.038 implicate thermogenic origins for these gases. Therefore, these reports provide evidence that nearby access to deep gas reservoirs has negatively impacted the quality of water in these wells. Any suggestion that water from these wells is safe for domestic use would be preliminary or inappropriate.

Non-zero concentrations of polycyclic aromatic hydrocarbons (PAH's) were reported in HW-02, HW-04, HW-06 and HW-8a; they included anthracene, benzo(a)pyrene, benzo(g.h.i)perylene, dibenzofuran, phenanthrene and pyrene. These PAH's are significant carcinogens at any concentration. Further, non-zero concentrations of chloroethane and chloromethane were found in HW-12, the water well with the highest ethane and methane concentrations of all those reported here. Although not classifiable as human carcinogens, these chemicals may harm organs including heart, kidney and brain. Therefore, the use of water from these five wells without further testing to establish biochemical safety would be inappropriate.

Supra-MCL levels of arsenic, fluoride, lithium and sodium (in addition to ethane and methane) were found in well HW-06. This particular combination of analytes would be consistent with the introduction of gas drilling / hydraulic fracturing additives into this water well. Therefore, further study of this possibility is warranted.

In summary, the decision of the USEPA to certify these six wells in Dimock, PA as "safe" was, in this reviewer's opinion, extremely premature and without foundation.

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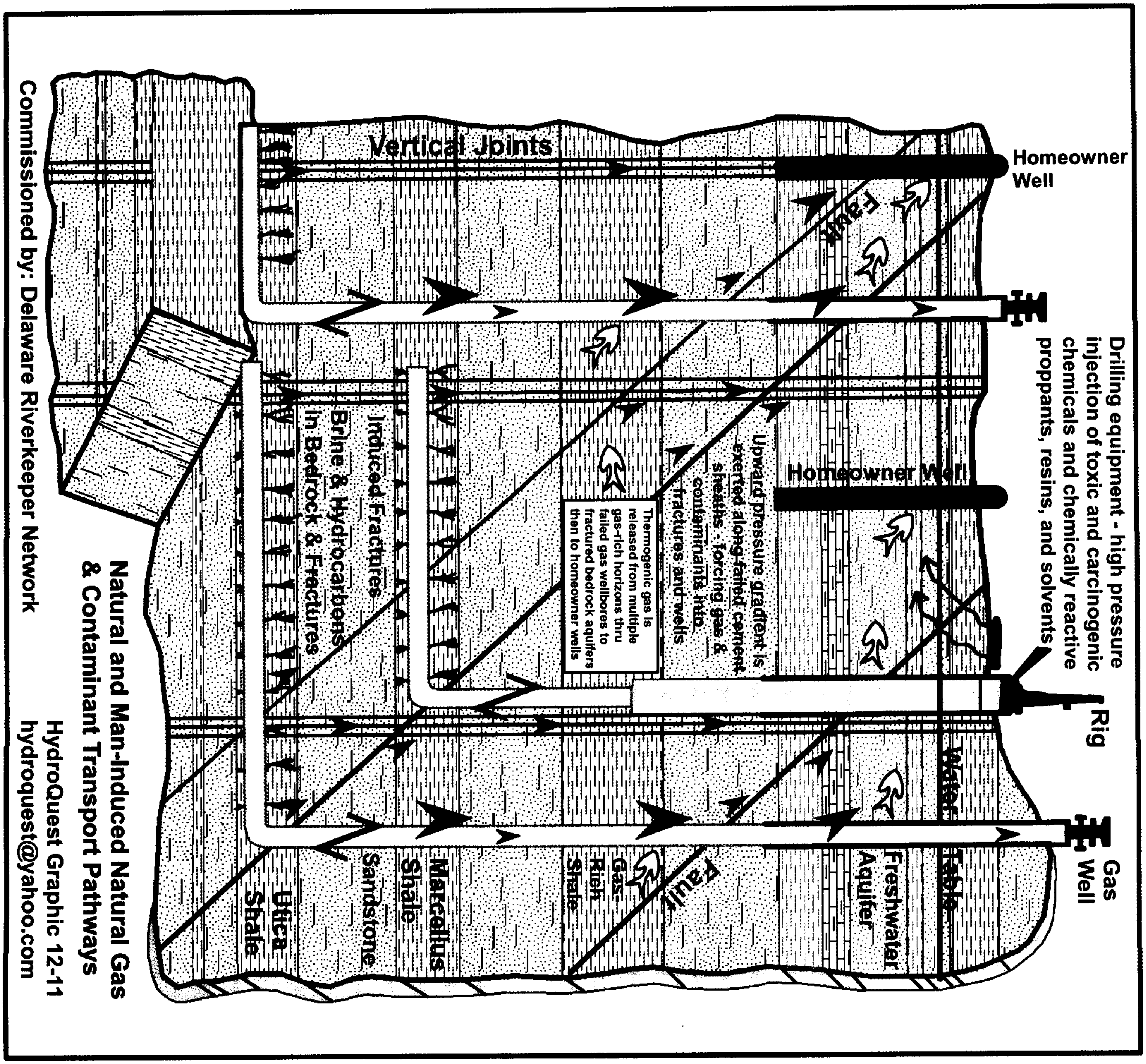

Homeowner Well
Drilling equipment - high pressure injection of toxic and carcinogenic chemicals and chemically reactive proppants, resins, and solvents
Rig
Gas Well
Vertical Joints
Fault
Homeowner Well
Upward pressure gradient is exerted along failed cement sheaths - forcing gas & contaminants into fractures and wells
Thermogenic gas is released from multiple gas-rich horizons thru failed gas wellbores to fractured bedrock aquifers then to homeowner wells
Induced Fractures
Brine & Hydrocarbons in Bedrock & Fractures
Water Table
Freshwater Aquifer
Fault
Gas Rich Shale
Marcellus Shale
Sandstone
Utica Shale
Natural and Man-Induced Natural Gas & Contaminant Transport Pathways
HydroQuest Graphic 12-11
hydroquest@yahoo.com
Commissioned by: Delaware Riverkeeper Network

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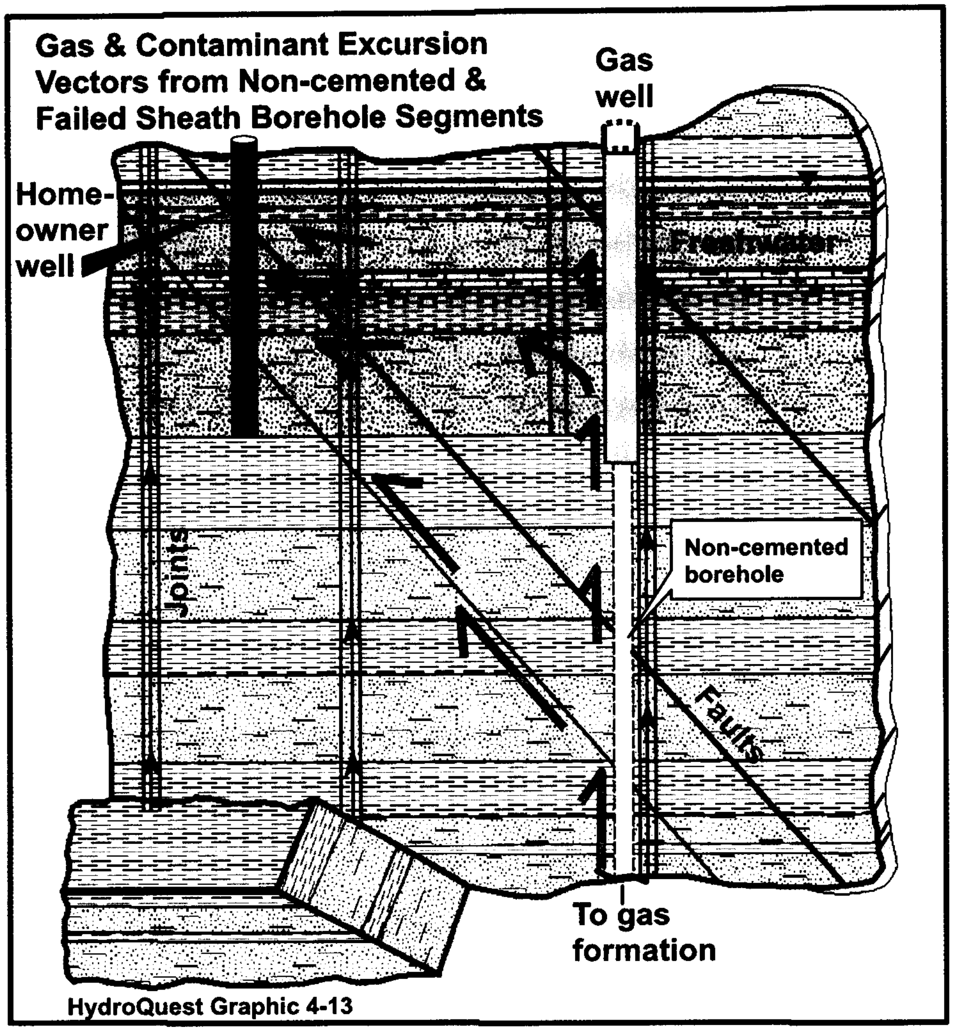
Gas & Contaminant Excursion Vectors from Non-cemented & Failed Sheath Borehole Segments
Gas well
Home-owner well
Freshwater
Joints
Non-cemented borehole
Faults
To gas formation
HydroQuest Graphic 4-13

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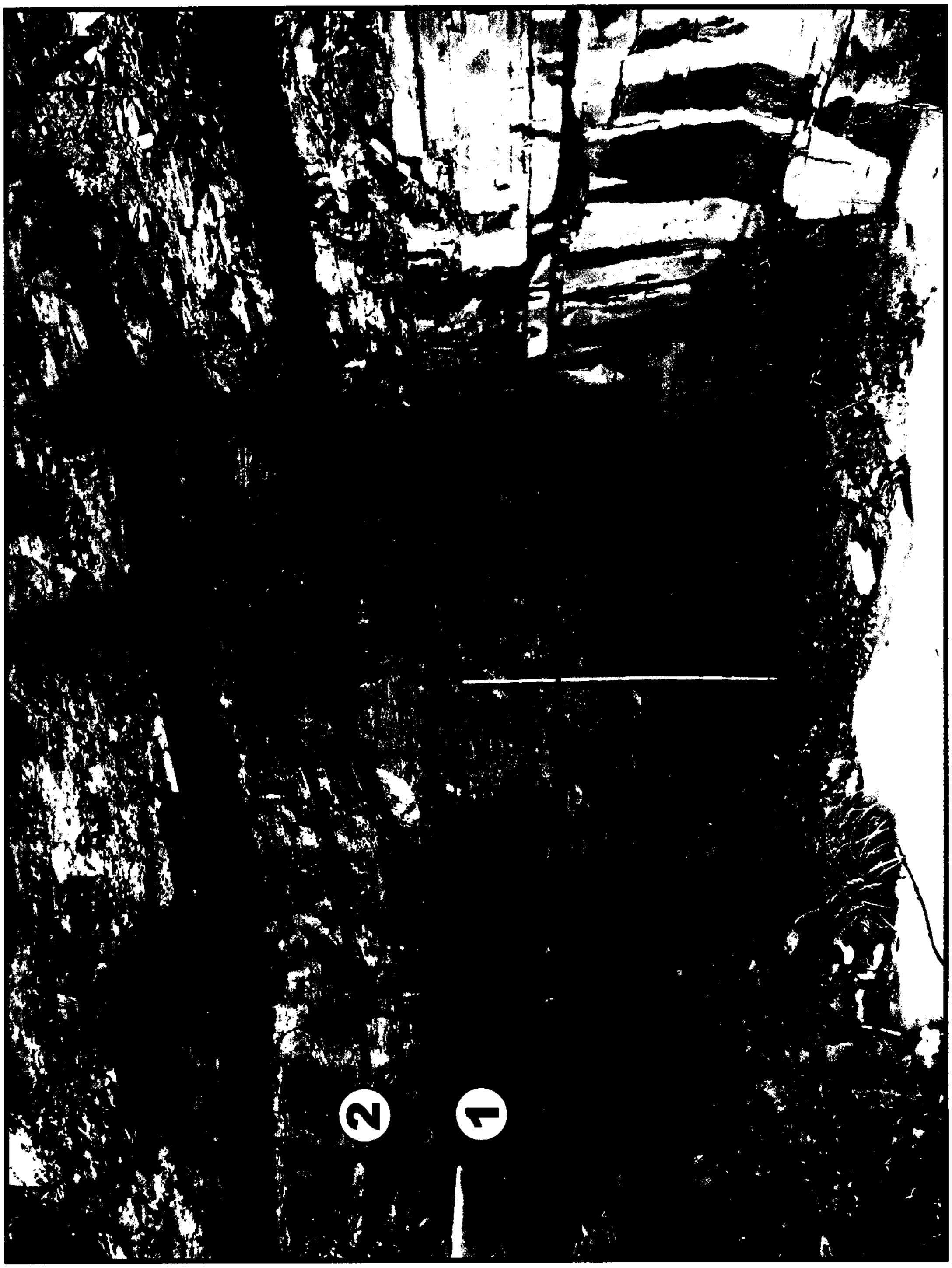
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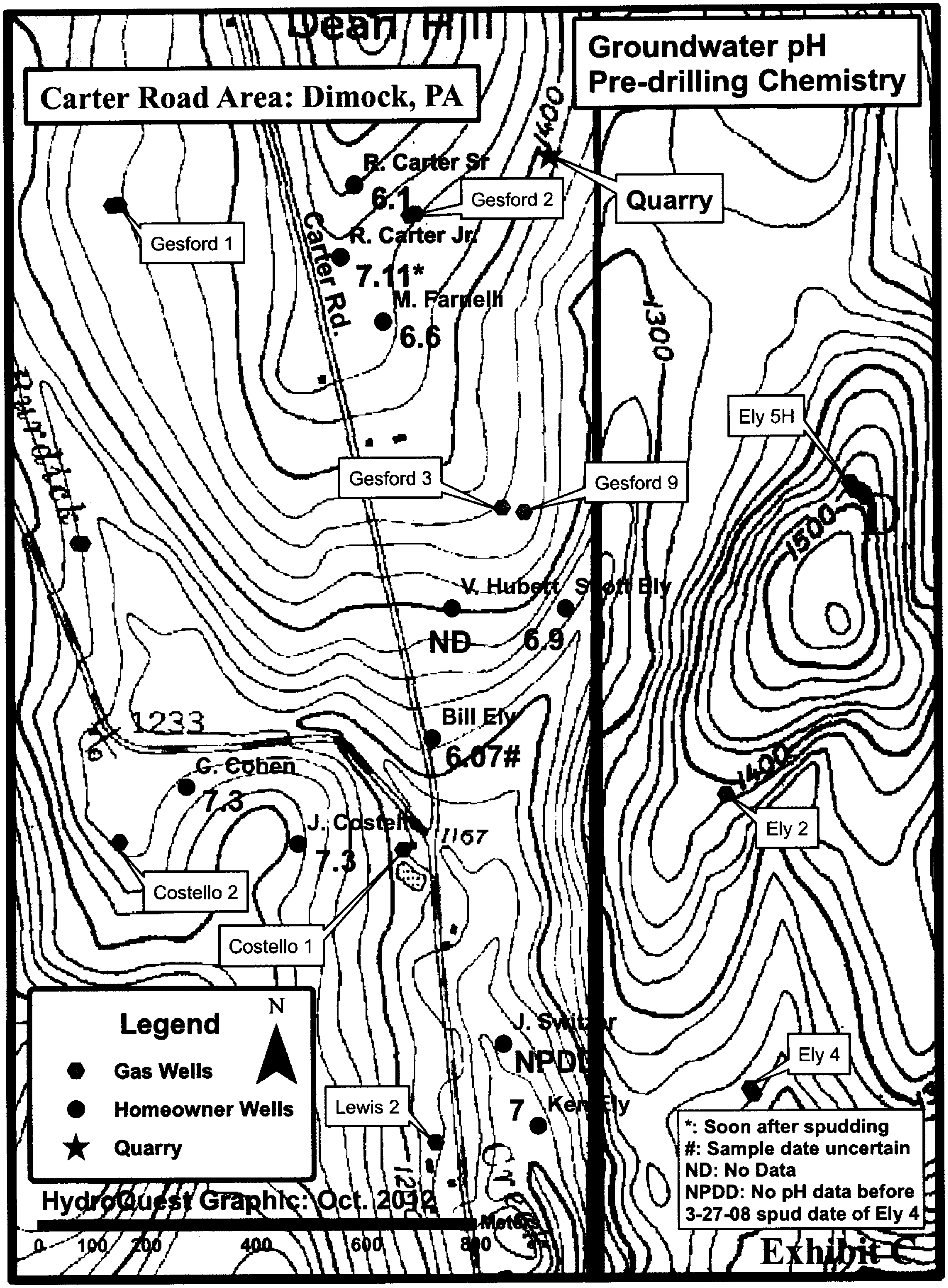
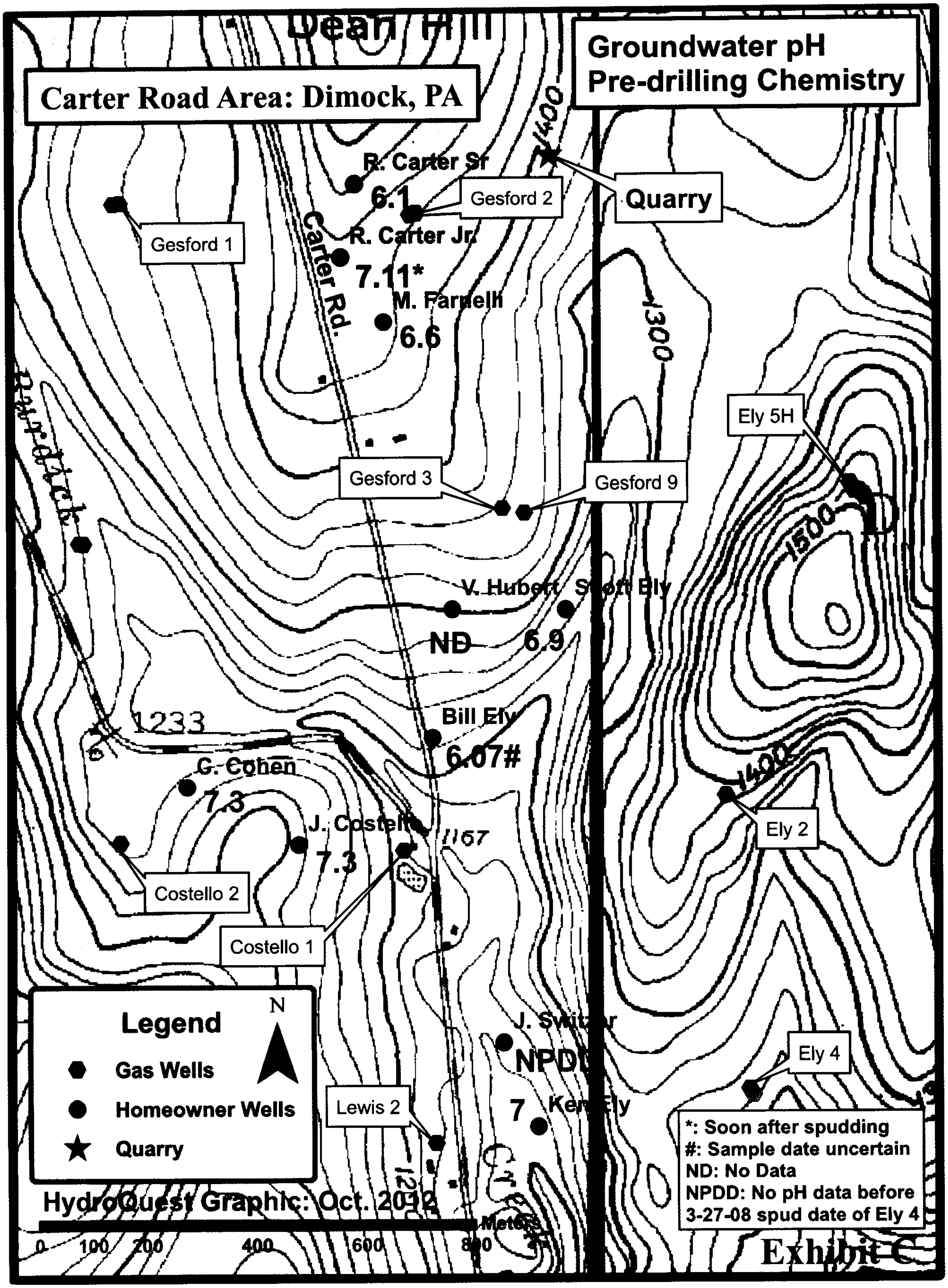

Carter Road Area: Dimock, PA
Groundwater pH
Pre-drilling Chemistry
Dean Hill
Quarry
R. Carter Sr
6.1
Gesford 2
Gesford 1
R. Carter Jr.
7.11*
Carter Rd.
M. Farnelli
6.6
1400
1300
Ely 5H
Gesford 3
Gesford 9
1500
V. Hubert
Scott Ely
ND
6.9
1233
Bill Ely
6.07#
G. Cohen
7.3
J. Costello
7.3
1167
Ely 2
Costello 2
Costello 1
Legend
N
Gas Wells
Homeowner Wells
Quarry
J. Switzer
NPDD
7
Ken Ely
Lewis 2
Ely 4
*: Soon after spudding
#: Sample date uncertain
ND: No Data
NPDD: No pH data before
3-27-08 spud date of Ely 4
HydroQuest Graphic: Oct. 2012
0 100 200 400 600 800 Meters
Exhibit C

Paul Rubin - Hydrologist
EXHIBIT 7A

Rubin

K


Carter Road Area: Dimock, PA
Groundwater pH
Pre-drilling Chemistry
R. Carter Sr
6.1
Gesford 2
Quarry
Gesford 1
R. Carter Jr.
7.11*
Carter Rd.
M. Farnelli
6.6
1400
1300
1500
Ely 5H
Gesford 3
Gesford 9
V. Hubert
Scott Ely
ND
6.9
1233
Bill Ely
6.07#
G. Cohen
7.3
J. Costello
7.3
1167
Ely 2
Costello 2
Costello 1
Legend
N
Gas Wells
Homeowner Wells
Quarry
J. Switzer
NPDD
Ely 4
Lewis 2
7
Ken Ely
*: Soon after spudding
#: Sample date uncertain
ND: No Data
NPDD: No pH data before
3-27-08 spud date of Ely 4
HydroQuest Graphic: Oct. 2012
Meters
0
100
200
400
600
800
Exhibit C

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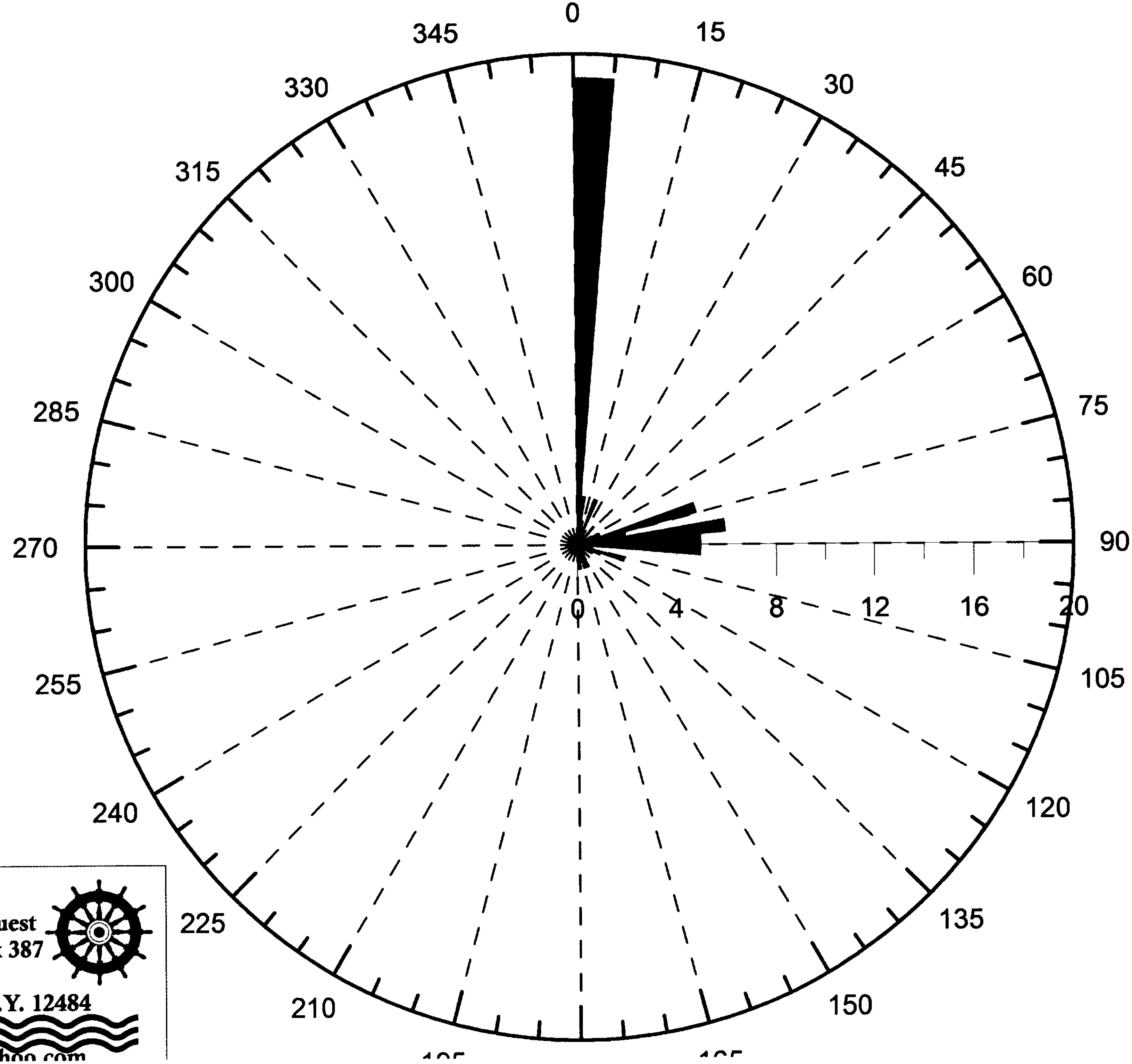
Carter Road Quarry, Dimock PA



HydroQuest
P.O. Box 387
Stone Ridge, N.Y. 12484
845-657-8111
hydroquest@yahoo.com

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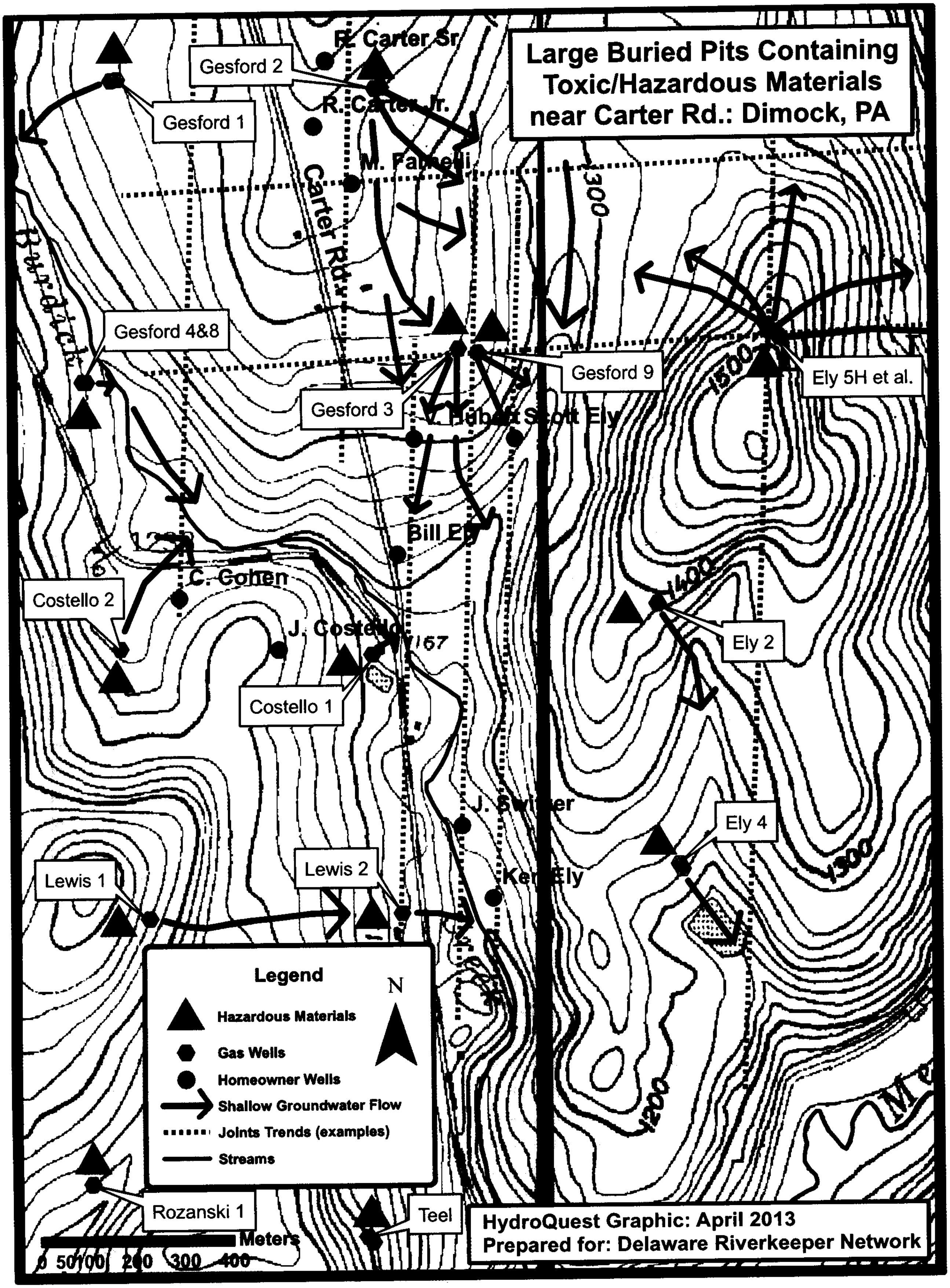

Large Buried Pits Containing Toxic/Hazardous Materials near Carter Rd.: Dimock, PA
R. Carter Sr.
Gesford 2
R. Carter Jr.
Gesford 1
M. Farnelli
Carter Rd.
Burdick
Gesford 4&8
Gesford 9
Ely 5H et al.
Gesford 3
Hubbert Scott Ely
Bill Ely
C. Cohen
Costello 2
J. Costello
Costello 1
Ely 2
J. Switzer
Ely 4
Lewis 1
Lewis 2
Ken Ely
1300
1500
1400
1300
1200
Legend
N
Hazardous Materials
Gas Wells
Homeowner Wells
Shallow Groundwater Flow
Joints Trends (examples)
Streams
Rozanski 1
Teel
Meters
0 50100 200 300 400
HydroQuest Graphic: April 2013
Prepared for: Delaware Riverkeeper Network

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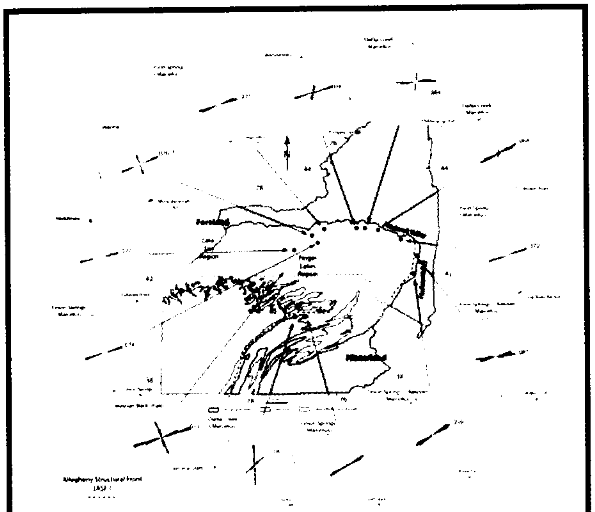
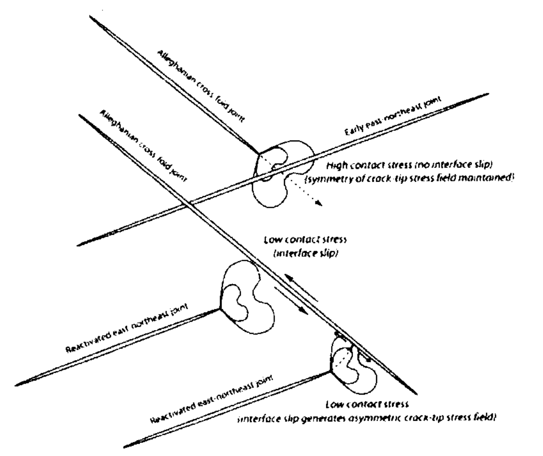
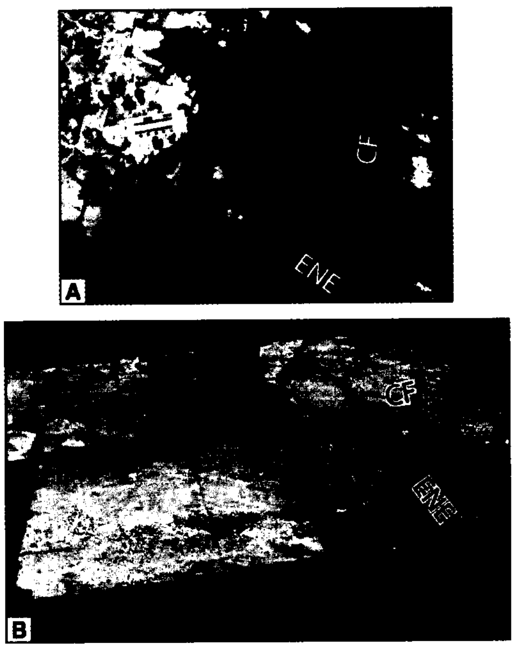


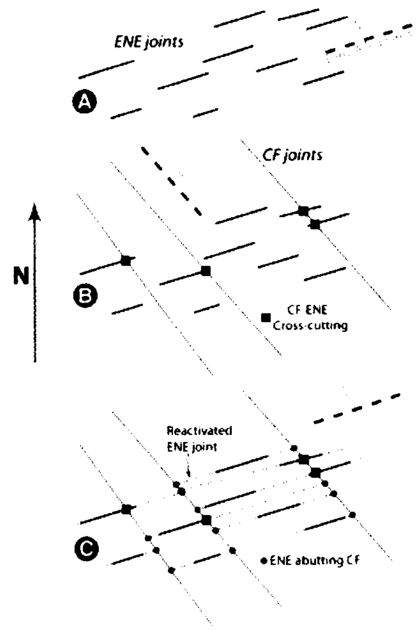
From Engelder et al. (2009)



From Lash and Engelder (2009)



From Lash and Engelder (2009)



From Lash and Engelder (2009)

Exhibit N. Figures from Engelder et al. (2009) and Lash and Engelder (2009) depict dominant joint orientations throughout the Appalachian Basin. Major joints strike east-northeast (J1 joint set) with younger cross-fold joints striking northwest (J2 joint set). The J1 joint set is more closely spaced and permeable than the J2 set. Exploration and other gas wells seek to intersect as many joint sets as possible, thereby maximizing productivity.

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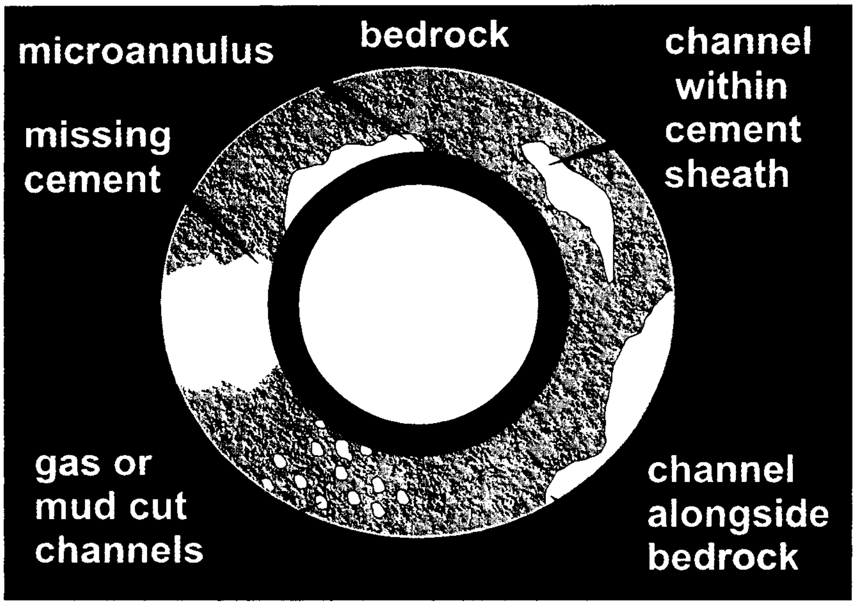
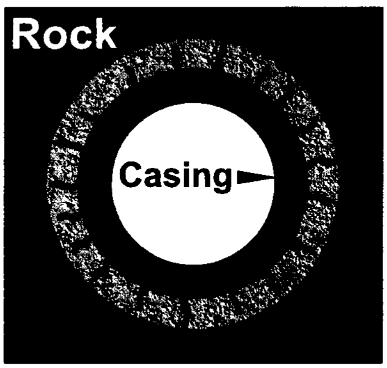
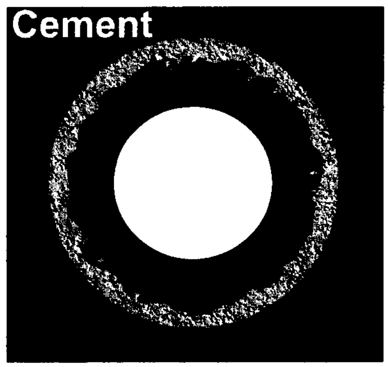


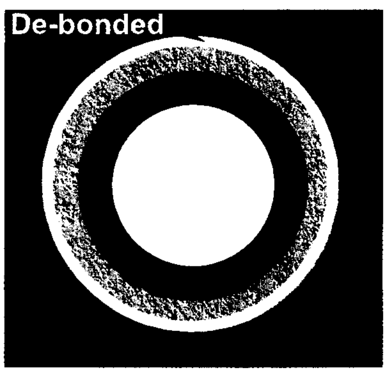
Types of cement channels in annular spaces that may permit upward methane migration. From Newhall (2006).



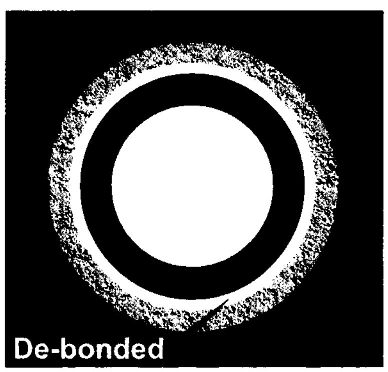
Cracks in cement sheath.



Plastic deformation in cement sheath.



Debonding at rock/ cement interface.



Debonding at cement/ casing interface.

Figure 2. Well operations may lead to loss of zonal isolation resulting from failure of the cement sheath. Some failure mechanisms are depicted. From Ravi et al. (2002). HydroQuest Graphic

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Some Concerns about Hydrofracturing in Shale-Gas Production

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Introduction

There are several compelling arguments in favor of gas drilling of shale beds in eastern states, with yields enhanced by hydraulic fracturing:

It's good for the economy.
It creates jobs.
It will supply the country with much-needed (and relatively clean) energy.

But there are arguments against this plan:

It's bad for the economy (not to mention infrastructure and quality of life).
Jobs will be mainly for trained outsiders.
We don't need the energy at present (there's now a glut of natural gas).
It endangers water supplies.

I'd like to briefly outline the economic aspects, but also explain the serious dangers of hydrofracturing from a hydrologic standpoint. I should point out that I am a professional groundwater hydrologist (see CV at end), and that I have also worked as a consultant to several oil and gas companies (e.g., ARCO, Plano, TX, now part of BP Group; Stone Energy Corp., Columbus, OH) and know and collaborate with hundreds of petroleum geologists. Therefore, I have no inherent bias against the oil industry.

A Few Economic Points

There is a great rush to drill now, not later. From the standpoint of petroleum companies and a number of lucky landowners, this makes economic sense from the standpoint of capital gains. But from the standpoint of state and local government, long-term prosperity, drilling and monitoring standards, and economic benefit, this is the worst time to drill.

1. The price of fuel is relatively low now. Think the price is high now? Just wait and see.
2. There is now such a glut of natural gas from drilling in the East that it is being piped to states farther west, and there are plans to sell it overseas.
3. Strategically, it makes economic sense to wait until there is a real need. The gas is not going to go away, and its value will only appreciate – until a cheap and reliable source of renewable energy is developed.
4. By waiting, instead of rushing in, it's possible to learn from early mistakes. Technology and safety will improve, and strategies for optimizing yield will have matured.

A Cultural Point

Gas drilling is pitting neighbor against neighbor, towns against the state, etc. This is an unhealthy situation where a few people benefit and everyone else suffers. This point can be exaggerated, but the effects are already being felt even where fracking has not yet begun.

And a Serious Message about Water Quality

Gas drilling and fracking have been given the green light in many areas, with three conditions: (1) the state environmental agency (e.g., DEC in New York and West Virginia, DEP in Pa.) will oversee the operation and ensure that their regulations are being followed; (2) that water quality will be monitored in the vicinity; and (3) that if contamination is detected, remedial measures will be taken. Why doesn't this satisfy the anti-frackers?

1. State agencies are underfunded and understaffed, and although they are fine and dedicated professionals, they are being placed in an impossible situation. There is nowhere near enough time, enough money, and enough expertise to adequately fulfill any (let alone all) of the mandates.
2. Problems around the country center on degraded water supplies and inadequate remediation and/or compensation. Monitoring of water quality involves measuring a few key contaminants (and many irrelevant items). Many people in and around drill sites, including neighbors with no financial involvement, complain about degraded water supplies – their water "tastes funny" is one of the most common complaints – and yet more often than not their water passes EPA standards. The problem is that not all the fracking fluids are known (for proprietary reasons), although this situation is improving. What do you test for? Methane itself is not a health risk except at very high concentrations (when explosions are among the risks). It is not even on the EPA list of drinking-water standards (*water.epa.gov/scitech/drinkingwater*). Non-threatening problems involving smell, taste, turbidity, etc., are apparently not technically considered contamination.
3. There are several scenarios for contamination: (a) spills at the wellhead; (b) breaks in the casing; (c) deep-seated contamination that migrates over time; (d) spills during transport.
4. If contamination is detected, what are the remedial measures? Just the surface contamination alone can be difficult to monitor and remediate. The deeper ones are far more serious, because not only are they very widespread, but complete remediation is impossible (given present technology and budgets). Even after most of the fracking fluids have been recovered, many contaminants will linger and disperse. By the time contamination is detected, it is often too late to remediate the entire zone of contamination. And more often than not, when contaminants are found, they still lie within the standards for drinking water.

These scenarios have recurred in many areas (e.g., Pa., Texas, Wyoming….). People are stuck with water that's "OK" but which they can't stand to use. Air quality is degraded by a persistent smell. But everything is fine because the standards for air quality are not exceeded. These problems also affect people who object to gas drilling in their region.

The weak standards to which gas drillers are held is a travesty. No private individual would be allowed to violate EPA standards in the way that fracking operations do legally. Since fracking and fracking fluids are presently exempt from EPA standards (thanks to lobbying efforts), and their compositions are proprietary, how can effective monitoring methods be established?

… and the Most Serious Problem of All

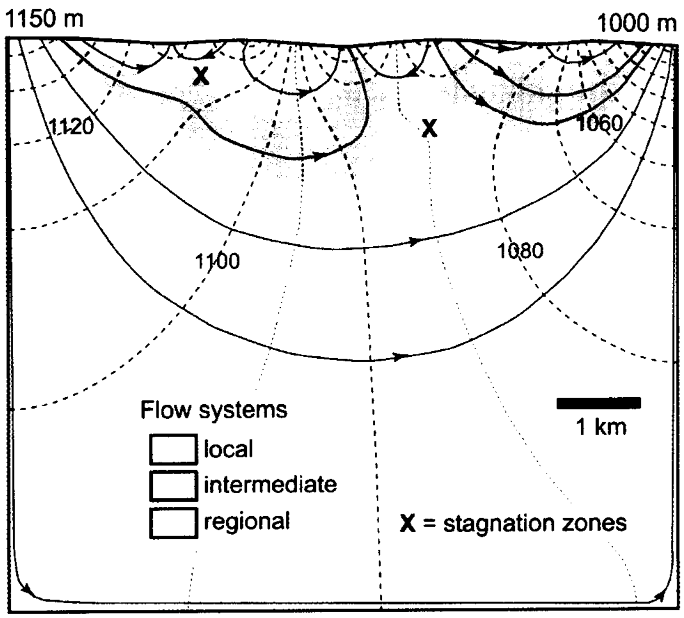
Fracking fluids are injected at depths of thousands of feet, way below the depth of water wells. Also, most of the fluids are extracted after the fracking. But residual fracking fluids remain – it is almost impossible to pump them all out. These supposedly remain in place, deep beneath the surface. Not true – they move.

Any groundwater hydrologist knows that groundwater flow is not limited to shallow depths. The patterns and physics of flow have been quantified since the early 20th century and have been verified many thousands of times in the field. Even if there are no problems in and around drilling sites, the contaminants will move

slowly but inevitably down-gradient to the major river valleys. In the Appalachians, that happens to be where most of the population centers and highest-yielding aquifers are located. Drilling will probably not take place in the valleys, but they are the areas in most serious danger from the contaminants. This is not raising a false alarm, but as close to a scientific fact as it is possible to get in the field of subsurface geology.

This needs to be put in perspective. Thick plumes of deadly toxic waste will not overwhelm these areas, but instead there will be small amounts of leakage over many decades and even centuries. It's possible that the contaminants will become so diluted that they will remain below drinking-water standards. But why should we impose this kind of low-level contamination on a large percentage of our population? This kind of contamination has a vile history. There are many examples where the toxic effects of contaminants were not realized until far too late – remember DDT, PCBs, thalidomide, etc? Remember Times Beach, Missouri? Love Canal, New York? The CDC lists hundreds of low-level contaminants in human bodies just from casual exposure. Just what we need is additional contaminants injected into the ground, where it will be literally impossible (both physically and economically) to remove them. If fracking becomes like a gold rush, with landowners grabbing for royalties to keep ahead of their neighbors, there will be widespread plumes of chemicals at depth. They will lie below the level of water wells, but that does not solve the problem.

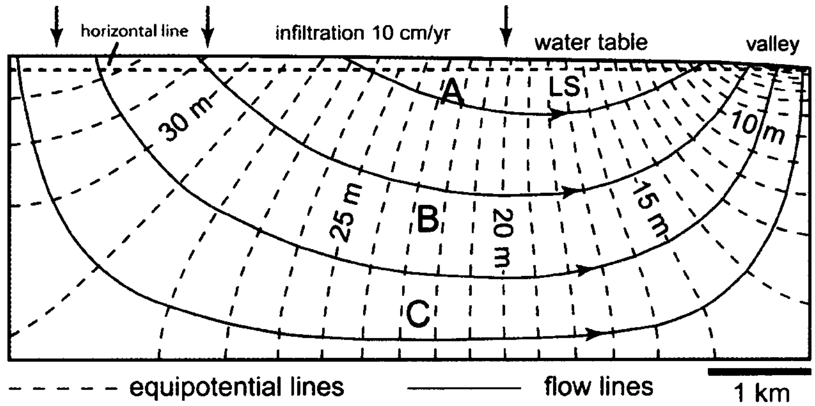
Patterns of groundwater flow have been recognized for well over a century, and for the past 70 years or so they have been quantified with the aid of physical laws and validated all over the world (early references: Hubbert, 1940; Tóth, 1963). Below is an example of Tóth's determination of groundwater flow patterns, showing local, regional, and intermediate-scale flow systems. Contaminants simply follow the arrows. They cannot disperse in the upstream direction unless there is almost no flow. Water infiltrates through upland surfaces and flows downward, laterally, and finally upward toward valleys:



The dotted lines show the distribution of hydraulic head, across which the flow moves (from high head to low head). Follow any of the solid lines to see where the flow and contaminants will go. The vertical scale is not exaggerated.

How fast do the water and contaminants move? This also involves well-established physical laws, but detailed answers are difficult to obtain because the behavior of subsurface rocks is known precisely

only where there are many wells and dye traces. A simplified example shows examples of how fast the contaminants can move in a typical groundwater system:



This was designed with the computer software package MODFLOW (U.S. Geological Survey). There is no vertical exaggeration. It represents the typical pattern of groundwater flow from an upland into a valley (left to right). The land surface is not shown, because only the groundwater pattern is critical. Groundwater is fed by infiltration throughout the region, and emerges in a valley at the upper right-hand corner. The water-table slope is the result of 10 cm/yr infiltration into rocks with an average hydraulic conductivity of 10^{-4} cm/sec. This is typical of sandstone, one of the most common subsurface materials in the Appalachians. In shale the conductivity is usually about 100 times lower, but hydraulic fracturing would increase this value. Furthermore, most contaminants would move out of the shale into adjacent more permeable rocks such as sandstone. In the Appalachians the infiltration rate may be up to about 5 times greater, depending on the local climate, soil type, and topography. A higher infiltration rate would produce a higher mounding of the water table above the valley, and proportionally faster groundwater flow, but the flow patterns would not change much.

How fast will contaminants move? Assume a typical porosity of 0.1 (10%). This is probably a little high, but a smaller porosity results in *faster* flow. Hydraulic conductivity (K), or permeability, is assumed to be 10^{-4} cm/sec (typical for sandstone, the most common aquifer material in the Appalachians). At A: local velocity is about 1.37 meters/year (4.5 ft/yr), and the average velocity all the way to the outlet is about 4.6 m/yr (15 ft/yr). At B and C the local velocities are a little lower, but all of the velocities increase greatly toward the valley because the flow is converging into a smaller area.

These velocities seem rather low. It would require several hundred years for contaminants to travel a mile. This sounds good if you don't mind your grandchildren having to deal with the problem. But this estimate is based on diffuse flow through a homogeneous material. The most rapid flow takes place through major fissures (joints, faults), and because the hydraulic head is lower in these efficient channels, groundwater in surrounding areas converges toward them, and they provide major channels for contaminants (see p. 8–11).

Consider a fracture system with an average width of 1 millimeter (0.1 cm), and a hydraulic gradient of 0.1 (100 m per km, common in the Appalachians). Flow velocity through a fissure is calculated by squaring the width (cm^2), multiplying by specific weight of water (980 dynes/cm^3) and hydraulic gradient (no units), and dividing by 12 and by the viscosity (about 0.013 dyne-sec/cm^2 at 50 deg. F). The velocity through this fissure will be approx. 6.28 cm/sec, which is equivalent to a flow of one kilometer in less than 5 hours! This gradient and fissure width are higher than average. At a gradient of 0.01 (10 m/km) the flow would be 1/10 as fast, and it would take 50 hours – not much consolation. Most fissures are narrower, more like 0.1 mm (0.01 cm), and

in combination with the smaller gradient this would provide a flow rate of 5000 hours per kilometer, or about 200 days. This gives us enough time to relax before the contaminants arrive.

But these fast-moving contaminants will still be fairly limited in volume, and some may degrade into harmless by-products. They could rapidly cause problems in some wells, but it will take hundreds of years for the entire contaminant load to drain. The contaminant level will rise slowly to a peak, and then subside even more slowly. In the meantime all the sand and gravel aquifers in the valley are susceptible to contamination. And residents in the valley will have no idea where the contaminants came from. The pollutants may be at only a low concentration, but this depends on how much has been injected into the ground and not retrieved. How much contamination takes place, and what it consists of, is beyond our control.

Typical groundwater models (such as the one used to construct the flow diagram) rely on average permeabilities from pumping tests. These inevitably underestimate the maximum rates of flow, which take place through interconnecting fractures. This discrepancy can be shown by comparing dye traces with the output of traditional groundwater models. Worthington et al. (2003) describe an example of aquifer contamination that cost 7 lives and caused sickness (some chronic) in 2000 people, where traditional groundwater models *underestimated* the flow rate by 50 to 70 times. The true rate of contaminant travel was demonstrated with dye tracing.

How common are these fractures? Do they really affect groundwater contamination? I live in Oneonta, New York, between the Susquehanna River and Otego Creek. Both river valleys have suspiciously straight patterns over long distances, which suggest fault control. But the valley bottoms are covered by up to 400 feet of glacial and river sediment, so its nearly impossible to determine the presence of faults. However, some water wells in the Susquehanna Valley south of Cooperstown contain measurable concentrations of methane, some (I am told) that are at flammable levels. A line of water wells in the Otego Creek valley have salt concentrations so high that the water is way past undrinkable (many thousands of parts per million). I was asked to investigate these. I figured that road salt was the source, until I found that the wells lay uphill from any roads. The only likely source of salt of this concentration is the Salina beds of Silurian age – which lie about halfway between the Marcellus Shale and the Utica Shale. Remediation is impossible in both areas, because the sources and dispersion are so widespread. Treating the problem where the groundwater emerges is like trying to cure blindness with a windshield wiper.

The impact of fracking fluids cannot be easily predicted from short-term measurements of water quality in the vicinity of the wells. Although the impact of individual fractures delivering wastes to nearby river valleys cannot be predicted so easily as suggested here, this analysis shows that there is real potential for contamination in surrounding river valleys well within our own lifetimes.

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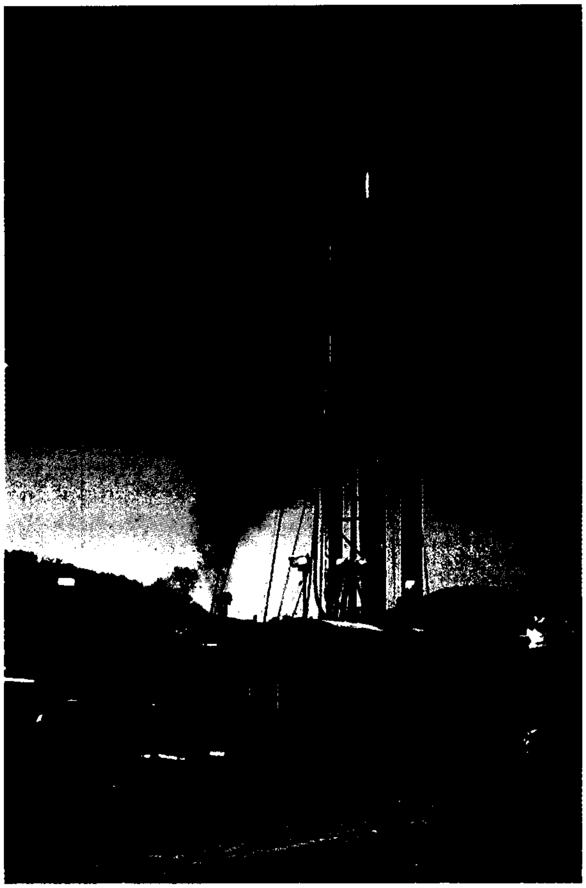
Tóth, J., 1963, A theoretical analysis of groundwater flow in small drainage basking: Journal of Geophysical Research, v. 68, p. 4795–4812.

Worthington, S.R.H., Smart, C.C., and Ruland, W.W., 2002, Assessment of groundwater velocities to the municipal wells at Walkerton, Ontario: Proceedings of 2002 joint annual conference of the Canadian Geotechnical Society and Canadian chapter of the International Association of Hydrogeologists, Niagara Falls, Ontario, p. 1081-1086.

A.N. Palmer: Brief Credentials

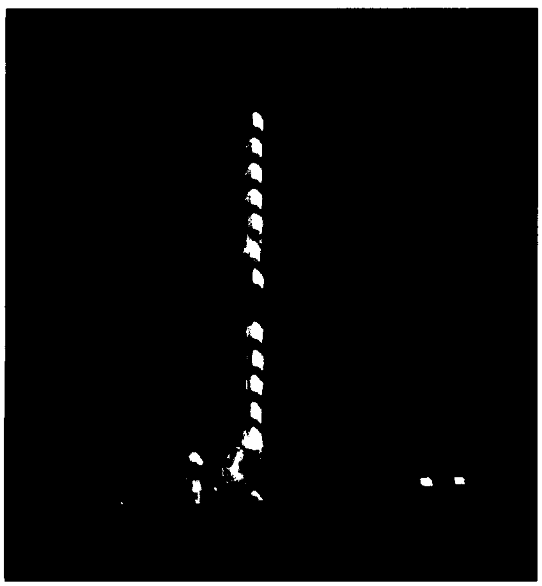
Former director of Water Resources program at SUNY Oneonta: largest program of its kind in the Northeast (*www.oneonta.edu/academics/earths/*).
Internationally recognized as an authority in the field of groundwater in fractured bedrock (see *www.iah.org/karst/members.html*).
Author of about 100 technical papers in groundwater flow in soluble rocks (e.g. Geological Soc. of Amer. Bulletin, v. 103, Jan. 1991, p. 1–21) and author or editor of several books.
Development of several computer software packages designed to model groundwater flow and water chemistry (see GSA Bulletin article above).
Fellow of American Association for the Advancement of Science; Fellow and Kirk Bryan Award recipient, Geological Society of America.
Consultant for City of Oneonta, N.Y., concerning placement and testing of several municipal water wells.
Occasional consultant for several petroleum companies, e.g. ARCO (now part of BP group), Plano, TX, and Stone Energy Corp. (branch in Columbus, OH).

Photos on next page.



Gas drilling rig, Coshocton Co., Ohio, 1986

"Roughnecks" connecting drill stems



Gas drilling at night

Part of 4" drill core retrieved from ~8000 ft depth

These photos show the drilling of a vertical gas well, with no fracking. Photos by Margaret V. Palmer.

ADDENDUM: SHALE-GAS PRODUCTION IN KARST

Arthur N. Palmer

The conclusion in the previous document is that hydraulic fracturing poses a serious threat to groundwater quality, not only in the vicinity of the drilling site, but also in the entire down-gradient part of the groundwater flow system. Although the main injection of contaminants takes place thousands of feet below the surface, groundwater flow inevitably carries them laterally and then upward into major neighboring river valleys over periods of years to hundreds of years, tailing off for possibly thousands of years. In the Appalachians, the valleys are where most people live. The contaminants are widely dispersed, but they pose a low-level threat to health, especially when thousands of fracked wells are involved. This is a huge gamble. Perhaps the contaminants will pose no health hazard or will degrade to harmless materials with time. But if problems do develop – and they will take time to be recognized – there is no hope of remediating the situation. It is impossible, both physically and economically.

This addendum considers the influence of bedrock on groundwater flow, with emphasis on karst.

Effect of Rock Types and Structure

Recoverable shale gas is most concentrated in areas of relatively flat-lying beds, such as those of the Appalachian Plateaus. Bedding-plane partings are favorable for groundwater flow. Fractures that cut across the beds are equally favorable to flow. Competent rocks such as sandstone and limestone contain major fractures that are relatively widely spaced. They are also cleanly fractured, with well-defined walls, so that water can travel through with little resistance. Bedding-plane partings behave in the same way, and their spacing is proportional to the bed thickness. In shale, fractures and partings are closely spaced and narrow. Also, they tend to get clogged with disintegrated rock so that they resist fluid flow. This is why fracking is used so often for recovery of natural gas from shale – to increase the number of fractures, and to widen and prop them open.

The problem is not so much the leakage of contaminants through the shale, but leakage along the vertical fractures produced or enlarged by fracking, into adjacent high-permeability beds. From there, the groundwater flow is concentrated and relatively rapid. Groundwater flow (and any contaminants) are concentrated in the most transmissive rocks, as water in adjacent less-permeable rocks flows toward them. This principle has been known for more than a century and can be demonstrated with any groundwater analysis or well-field examination.

Problems in Karst

Caves and solution conduits in soluble rock (limestone, dolomite, evaporites) form along zones where groundwater flow is already most rapid. This means that most of them lie at shallow depth below the surface. However, deep caves can also form where rocks are faulted or folded. Cave systems that loop more than 1000 feet below the surface and emerge at springs are common in thick, deformed limestone such as that in Mexico. This is not common in the U.S., because limestones are rarely thick enough; and where they are (as in western Virginia) there are fewer reliable sources of shale gas. Most such areas are folded as well as faulted, so that much of the shale gas has been expelled or sequestered into small zones. In general, there is little problem of upward leakage of fracking contaminants exclusively through caves.

However, some deep caves and solutional zones have formed near the surface and were later buried by younger rocks, to form paleokarst. There is only one major paleokarst zone in the eastern U.S., at the boundary between Lower and Middle Ordovician rocks. The productive shales lie mainly above this zone; but downward leakage can take place into underlying paleokarst zones, where contaminants can be conveyed great distances laterally, and eventually to valley outlets. This is of concern mainly in the central and southern Appalachians, where the paleokarst is most extensive.

In typical karst areas in the East, most groundwater flow is shallow. This poses a problem for constraining the dispersion of contaminants at drill sites, e.g., from accidental spills, routine minor leakage, or from ruptured seals around wells (see reports by Paul Rubin, of Hydroquest). Ordinarily contamination from such spills moves slowly through low-permeability soil and rocks. But where karst is present, groundwater velocities are up to hundreds or even thousands of times greater. This has been shown with innumerable dye traces. Traditional computer models of groundwater flow fail to predict flow patterns and velocities in karst with any helpful degree of accuracy. The case history described on page 5 (Worthington et al., 2002) involved dolomite karst, where a quarter-million-dollar study with well tests and computer modeling, by one of the most trusted companies in the field, underestimated the flow velocity by 50 to 70 times and completely misinterpreted the contaminant catchment area.

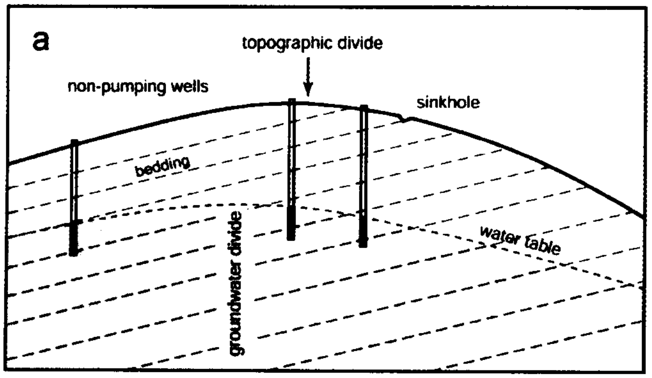
There are several problems with dispersion of contaminants in karst:

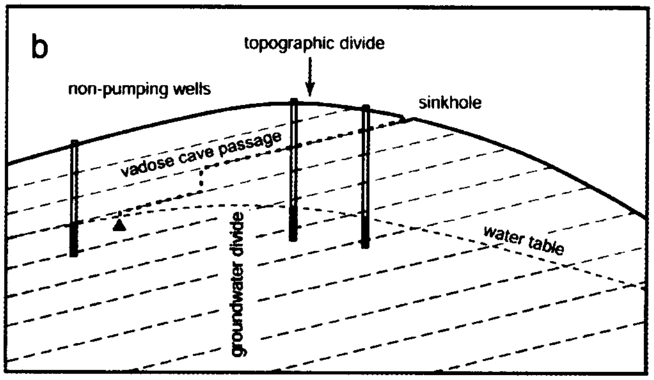
1. Concentration of flow along major flow paths. This is not necessarily bad, since it aids remediation – except that the contaminants will have flowed to surface springs before detection and remediation can take place.

2. High flow velocities (see #1).

But here are the really serious problems in karst:

3. At shallow depth, above the water table, underground water and contaminants move by gravity. They tend to get hung up on relatively low-permeability beds and move down the dip of the strata. This problem is greatest where the dip is small – as in the Appalachian Plateaus – because the contaminants can be dispersed over large distances. This gravitational water is independent of normal groundwater potential fields, so its presence cannot easily be detected. It can move beneath topographic divides, and even across groundwater divides that have been mapped by well data, and hit the water table far from where the surface contamination took place:

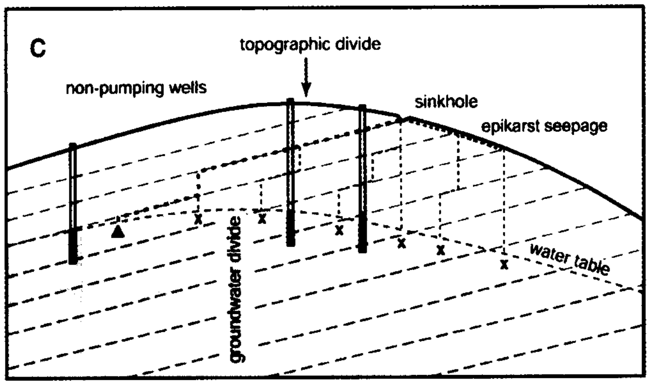




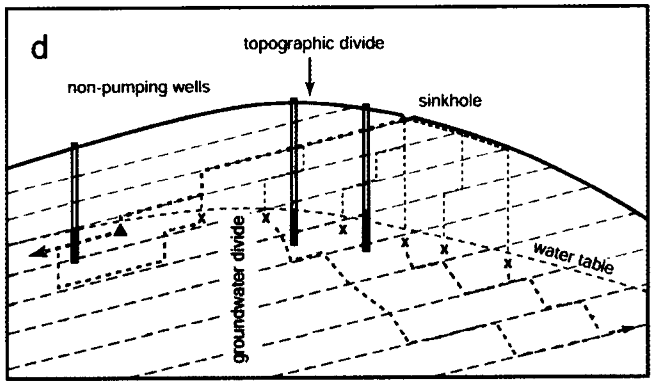
a. Information from drilling.

b. Contamination enters a cave through a sinkhole or adjacent spill. Note that in well-bedded rocks the main flow can easily cross beneath the topographic divide and over the groundwater divide. Even though it may jog downward along major fractures, it can reach the water table at remote points such as the triangle. Cave mapping and dye tracing in karst show this to be very common, and therefore somewhat predictable – but only to those who are aware of the problem. See next page....

Source: A. Palmer, 2007, Cave Geology: Dayton, OH, Cave Books, p. 390.

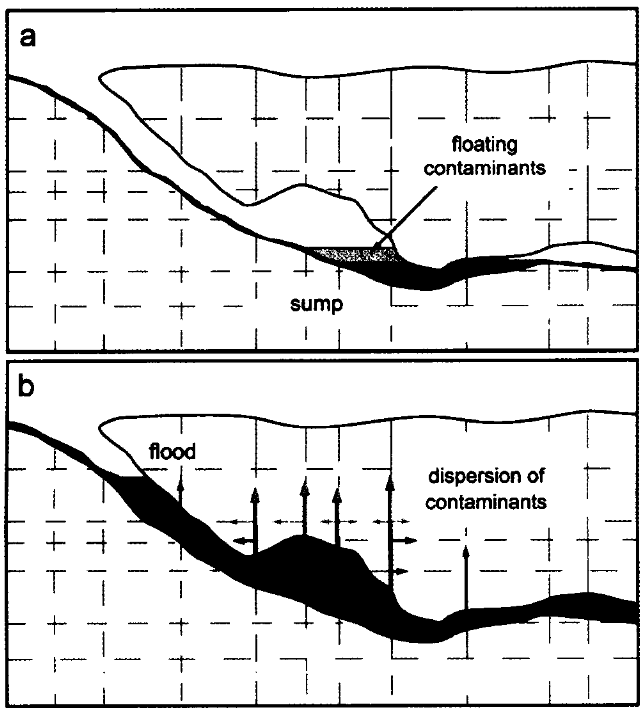


c. But downward seepage also takes place through all of the minor fractures, so some of the contaminants become widely spread and reach the water table at many points (X). This is a problem in all bedded rock, but is most serious in karst.



d. From those points of contamination (X), groundwater moves slowly down the hydraulic gradient along paths that are somewhat predictable, to valleys on either side of the plateau. But the contaminants are way beyond remediation, least of all at the spill site.

4. Many contaminants are "floaters" – liquids that are less dense than water. In karst conduits these tend to accumulate at sumps where cave water reaches a sump (ceiling drops below the water level). This material can remain and accumulate with time, with volatiles able to escape from solution and seep upward along fractures to the surface. This problem becomes much worse during floods, when water fills the caves and forces the contaminants upward through many fractures, spreading them out. As a result the escape of volatiles can be much greater:



This can be a serious problem. Examples have been documented where accumulation of flammable volatiles (e.g., gasoline fumes) have reached potentially explosive levels in overlying buildings. Examples sites include Bowling Green, Kentucky (Crawford, 2001).

Methane (CH_4) is the lightest hydrocarbon and the least soluble of the common gases. By itself it is less likely to contribute to this kind of contamination, since the problem is with spills near the surface. However, leakage of methane from below can contribute to the problem illustrated here.

Source: A. Palmer, 2007, Cave Geology: Dayton, OH, Cave Books, p. 391.